COMPONENTS' AND MATERIALS' PERFORMANCE FOR ADVANCED SOLAR SUPERCRITICAL CO2 POWERPLANTS

Process Parameters of Solar Particle Cycle

Deliverable 1.2

WP1: Materials operation conditions and their feasibility studies

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ABOUT THE PROJECT

COMPASsCO$_2$ is a 4-year HORIZON2020 project started on 1.11.2020. It is led by the German Aerospace Center (DLR), with eleven additional partners from seven European countries.

COMPASsCO$_2$ aims to integrate CSP particle systems into highly efficient sCO$_2$ Brayton power cycles for electricity production. In COMPASsCO2, the key component for such an integration, i.e. the particle-sCO$_2$ heat exchanger, will be validated in a relevant environment. To reach this goal, the consortium will produce tailored particle and alloy combinations that meet the extreme operating conditions in terms of temperature, pressure, abrasion and hot oxidation/carburization of the heat exchanger tubes and the particles moving around/across them. The proposed innovative CSP sCO$_2$ Brayton cycle plants will be flexible, highly efficient, economic and 100% carbon neutral large-scale electricity producers.

The research focus of COMPASsCO2 is on three main technological improvements: development of new particles, development of new metal alloys and development of the heat exchanger section.

DISCLAIMER

This project has received funding from the European Union's Horizon 2020 Research and Innovation Action (RIA) under grant agreement No. **958418.**

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CSP	Concentrating Solar Power
EC	European Commission
EU	European Union
HX	Heat exchanger
PHX	Primary heat exchanger
LMTD	the logarithmic-mean temperature difference
sCO_2	Supercritical carbon dioxide
ASME	American Society of mechanical Engineers
LCOE	Levelized cost of electricity
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.
MAS	Maximum allowable stress
TES	Thermal energy storage

1 ABSTRACT

Work Package 1 of COMPASsCO2 is mainly focused on material operating conditions in an industrial environment and is divided into different tasks. This report concerns its second task, which is dedicated to the solar particle cycle including the particle- sCO_2 heat exchanger.

Deliverable 1.1 from this work package allowed us to define the process parameters of the two heat exchangers (a high pressure and a low pressure) for the particles and supercritical CO_2. Based on that information, two particle- sCO_2 tubular heat exchangers were designed. The heat exchangers' design consists in several bundles of horizontal tubes heated by a hot falling bed of bauxite particles. Four different alloys were assessed for the heat exchangers composition among which only two were able to withstand the high pressure and temperature encountered. These two alloys are Haynes 282 and Alloy 740.

For the given sCO_2 power block and heat exchanger, a solar particle system based on the CentRec® receiver technology was defined. This mainly comprises the heliostat field layout, the receiver geometry and the thermal energy storage system sizing. The DLR's software HFLCAL was used to determine parameters that define these subsystems, namely, the number and position of heliostats, receiver aperture area, tower height, particle temperatures and particle inventory. Furthermore, the heliostat field and the receiver design efficiency, respectively, was estimated for the design point and as an annual average. Additional relevant parameters for high-temperature component and particle development are discussed.

2 INTRODUCTION

The aim of this deliverable is to determine the operating conditions in the particle cycle, defined by the particle- sCO_2 heat exchanger (HX), the solar field, the receiver and the thermal energy storage (TES) system. The first part of this deliverable, therefore, concerns the development of a concept design of the particle- sCO_2 heat exchanger. The second part describes the preliminary design of the heliostat field layout, receiver geometry and TES system parameters. The schematic of the overall system is depicted in Figure 1; it should be mentioned that the sCO_2 cycle shown is not corresponding to the cycle selected and presented in Deliverable 1.1, this figure is only to illustrate the relationship between the solar plant and the power block.

A description and selection of the sCO_2 Brayton cycle has been provided in COMPASsCO2 Deliverable 1.1 "Process parameters of solar sCO_2 Brayton cycle".

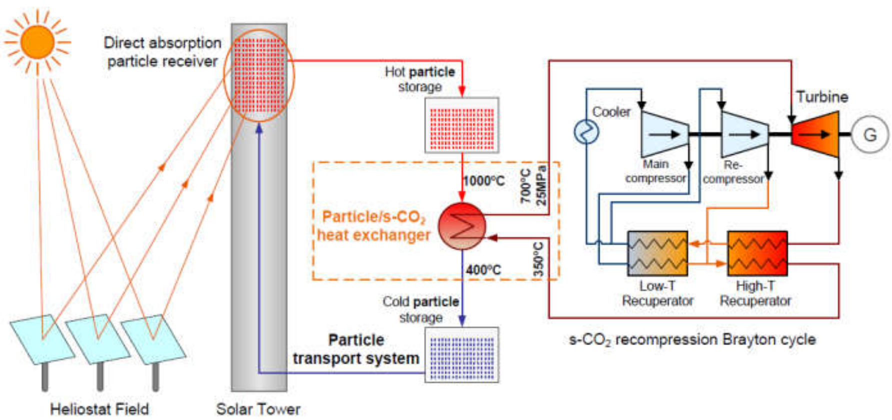


Figure 1: Schematic of a Particle-sCO2 CSP plant.

2.1 Particle-sCO_2 Heat Exchanger

The particle-sCO_2 heat exchanger concept is characterized by a moving bulk of particles that flows top-down through bundles of horizontal tubes. The sCO_2 at high pressure circulates through the tubes and is heated up by the hot particle flow. As the particles at the heat exchanger inlet reach 900°C, it is important to select noble alloys that can withstand this high temperature and also the daily thermal gradient during the start-up and shut down of the plant. In addition to the high temperature and pressure levels, the materials of the heat exchanger are exposed to erosion from the particle side and corrosion and oxidation from the sCO_2 side.

2.2 Solar Particle Loop

The solar particle loop provides and stores the thermal energy needed to power the particle-sCO_2 HX and, therefore, to the power block. It consists of the heliostat field, a thermal receiver on top of a tower, a vertical particle transport system and the thermal energy storage (TES) system. Depending on the size of the plant and the employed receiver technology, several heliostat fields, towers and receivers can be combined to feed a single heat exchanger and power block. The TES system can then either be decentralized, with hot and cold storage tanks at each tower, or be located as a single system close to the power block.

Within the COMPASsCO2 Project, a centrifugal particle receiver, based on the CentRec® Technology (Wu, Amsbeck et al. 2014), is employed. This technology is based on a rotating drum covered by a thin layer of small particles on the inside (see Figure 2). This layer is directly irradiated with highly concentrated sunlight through the aperture opening of the drum. By adjusting the rotational speed of the drum, the retention time of particles in the receiver can be adjusted to achieve the desired outlet temperature. A prototype CentRec® Receiver has achieved particle outlet temperatures of more than 950 °C (Ebert, Amsbeck et al. 2019).

These high outlet temperatures would result in high losses in an external receiver. A cavity receiver, as is the CentRec®, can achieve much higher efficiencies but requires a high solar flux at its cavity, which can only be achieved with a polar field. As polar fields are more limited in size than surrounding fields, commercial size CSP plants employing the CentRec® technology will most likely be multi-tower configurations.

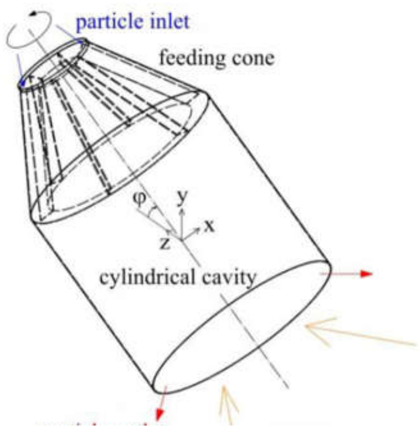


Figure 2: Principle design of the Centrifugal Particle Receiver (Wu, Amsbeck et al. 2014)

Besides the receiver and the heat exchanger, the particle loop consists of vertical and horizontal (at least in the case of multi-tower configurations) transport systems and the TES system. The latter is foreseen as several insulated tanks. For the vertical transport of particles, several options are conceivable, depending on tower height and required mass flow. The horizontal transport has been proposed to be conducted by (autonomous) trucks (Buck and Giuliano 2018). The parasitic consumption for both transport systems is expected to be lower than in state of the art CSP plants with molten salt as the heat transfer medium.

The detailed design of the solar particle loop is not in the scope of COMPASsCO2, as the components mentioned above are either on high TRL already (such as the receiver), or are being developed in other projects (such as the particle transport systems of decentralized tower systems). In this document the selection of the components is done in order to define the boundary conditions that affect the particle-sCO_2 HX on the particle side.

3 HEAT EXCHANGER CONCEPT DESIGN

3.1 Heat exchanger concept

The heat exchanger design consists in several bundles of tubes through which the sCO_2 flows. A moving bulk, composed of bauxite particles, flows top-down across the tubes bundles while heating them up. The concept of the heat exchanger is illustrated in Figure 3.

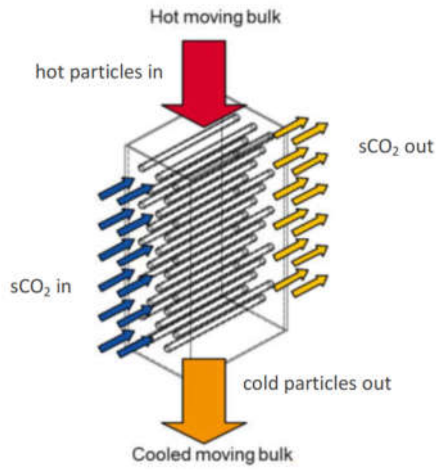
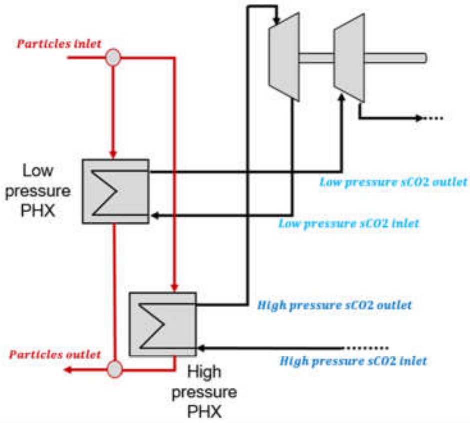


Figure 3: Heat exchanger concept [derived from (Buck and Giuliano 2018) based on (Baumann and Zunft 2015)]

3.2 Process parameters and technical limitations

As described in Deliverable 1.1, the selection of a Supercritical Partial Cooling cycle with Intercooling and Reheating lead to defining the process parameters values. Such a cycle requires two heat exchangers comprising a high pressure and a low pressure section. The process parameters are shown hereunder.



Parameters	Particles (high pressure PHX)	Particles (Low pressure PHX)	sCO2 (high pressure PHX)	sCO2 (low pressure PHX)
PHX inlet temperature [°C]	900	900	532.8	583.4
PHX outlet temperature [°C]	582.8	633.4	700	700
PHX inlet pressure [bar]	/	/	265.3	110.4
PHX outlet pressure [bar]	/	/	260	108.2
Mass flowrate [kg/s]	355.9	288.3	632.6	632.6

Figure 4: Process parameters of the heat exchangers

Those values were generated by a thermal model developed in Engineering Equation Solver (EES). The model is based on the logarithmic-mean temperature difference (LMTD) coupled with enthalpy balances. The thermal model considers the following aspects:

- The internal heat transfer coefficient between the sCO_2 and the tubes internal walls is computed according to a Nusselt correlation. The Nusselt number is calculated thanks to the equation (based on Gnielinski 2010, Eq. 28)

  $Nu = \frac{f*Re*Pr}{8*\left[(1+12.7*\left(\frac{f}{8}\right)^{0.5}*\left(Pr^{\frac{2}{3}}-1\right)\right]}$ where

  - $f = 9.343 * 10^{-3}$ is the tube internal friction factor for a smooth tube
  - Re and Pr are the Reynolds and Prandtl number, respectively.

  The calculated internal heat transfer coefficient was found to be around 9000 W/(m²*K). This coefficient is rather high because of the sCO_2 velocity that was set at 40 m/s inside the tubes. For mechanical reasons, the sCO_2 velocity magnitude had to remain under a limit of 45 m/s.

- The tube conduction resistance is taken into account and was revealed to have a non-negligible impact on the thermal behavior of the system.
- The external heat transfer coefficient (between particles and the tube walls) based on previous experiences by the project partners is fixed to 200 W/(m²*K).

3.3 Material selection

3.3.1 Selection of an alloy for the HX

Different alloys were considered for this application. The following table shows the different alloys that were assessed and the possibility to use them or not for the heat exchanger. Each alloy was evaluated at the expected pressure (up to 265 bar) and temperature according to ASME VIII division 1 code. Two of the alloys showed too low maximum allowable stress (MAS) values to withstand the operating conditions.

Table 1: Material selection based on the ASME code

Alloy denomination	Verification with the ASME VIII division 1 (2019 version)
Sanicro 25	MAS too low
Alloy 617	MAS too low
Alloy 740	MAS high enough
Haynes 282	MAS high enough

Only Alloy 740 and Haynes 282 satisfied the ASME code. The material selection for the PHXs will be further discussed in Deliverable 1.3 of Work Package 1.

The heat exchanger basic design was done by considering the Alloy 740 for the tubes with a heat conduction coefficient of $20.7 \frac{W}{m*K}$ which was evaluated at the design temperature. Regarding the tube thickness, the lowest possible thickness that verifies the ASME recommendations was used. Indeed, the smaller the thickness is, the better the heat exchange between the particles and the sCO_2 is. The tubes diameter was therefore fixed to 30.8 mm with a 2.6 mm thickness which is a good compromise. A higher diameter would induce a higher thickness which is not wanted for thermal efficiency reasons. On the opposite, a too small diameter would require much more tubes for the final design of the HX.

3.3.2 Selection of the type of particles

The state of the art particles considered for the design are bauxite particles that actually are intermediate strength proppants. These particles are engineered to deliver superior conductivity and are characterized by a specific heat of $1200 \frac{J}{kg*K}$.

3.4 Heat exchanger design

The process parameters lead to one design for the high pressure PHX and to another design for the low pressure PHX. The selected alloy for the design also has an impact. Indeed, the choice of an alloy induces a tube minimum thickness to withstand the high pressure and temperature. As described in the previous section, the tube thickness has an impact on the thermal behavior of the heat exchanger. The design parameters are summed up in Table 2.

The inlet sCO_2 flow is divided into 208 sub-flows for the high pressure PHX (see Figure 5) and into 500 for the low pressure one. Each parallel branch is a planar coil (serpentine) that covers the whole height of the heat exchanger casing (see Figure 6).

Table 2: Heat exchanger geometrical configuration

Design parameter	Unit	High-pressure PHX	Low-pressure PHX
Tube external diameter	[mm]	30.8	30.8
Tube wall thickness	[mm]	2.6	2.6
Number of tubes in parallel	[-]	208	500

Tube length per row	[m]	10	4
Number of rows	[-]	33	25

Now that the geometrical configurations of the HXs are defined, the particles mean velocity can be assessed based on their mass flowrates, known from the heat balance (see Deliverable 1.1). The particles mean velocity in the high-pressure PHX is equal to 2.3 mm/s while it is equal to 2 mm/s for the low-pressure PHX.

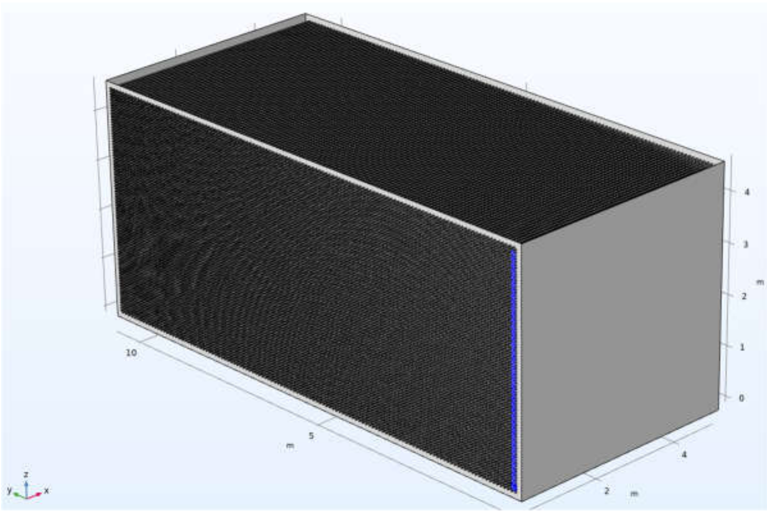


Figure 5: Sketch of the high pressure PHX

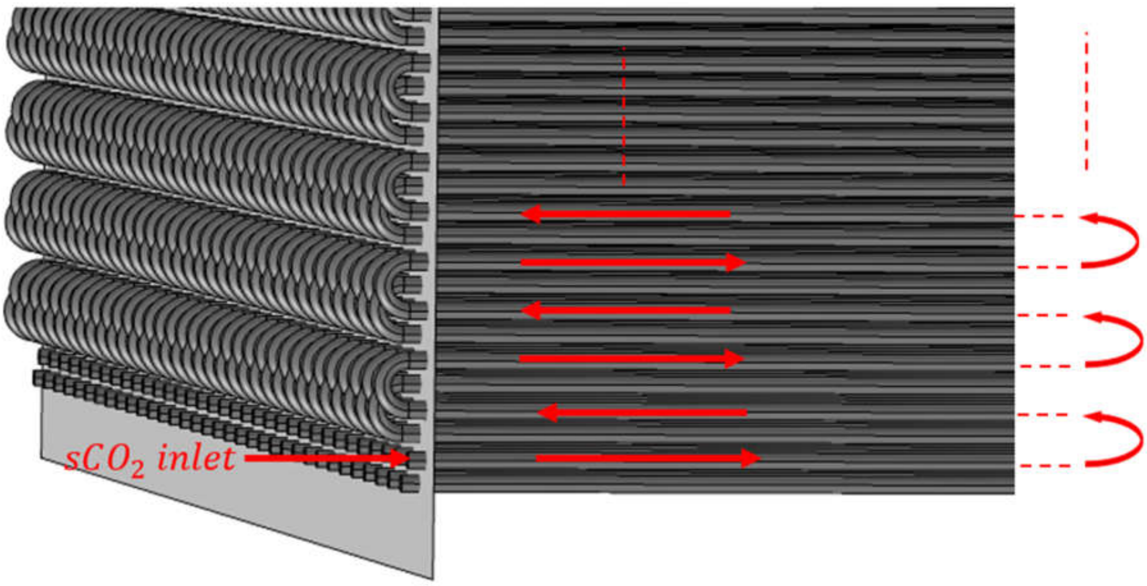


Figure 6: sCO_2 circulation in one parallel branch

The horizontal and vertical spacing between tubes was set based on previous experience of the project partners. The magnitude of the spacing between the tubes is important to avoid particles clogging inside the heat exchanger. This design will be verified with the experimental setups in WP5.

4 PRELIMINARY SOLAR FIELD DESIGN

The developed solar field design consists of several towers containing a single CentRec® receiver each and with an associated field of heliostats. The heated particles are transported from the towers to a central power block and returned at cold tank temperatures. In the following, such a plant is optimized using the DLR tool Visual HFLCAL (Schwarzbözl, Pitz-Paal et al. 2009) in Version 13 Beta.

4.1 Input Parameters

Certain parameters have to be defined a priori. For example, the size of the solar power plant is derived from currently developed commercial tower plants, as is its location. Receiver-related parameters are based on DLR-internal experience with the CentRec® technology and CSP plants in general. Particle temperatures at the HX are derived from its concept design (See Section 3). A list of all input parameters to the HFLCAL Model can be found in Annex 1, the most important ones are additionally presented in Table 3.

Table 3: Main input parameters to field optimization (dp: design point)

Parameter	Value	Comment [Source]
Location	Postmasburg, RSA	Location of Redstone Solar Thermal Power Plant Project
Power block net rating	112.8 MW_e	Based on cycle chosen in Deliverable 1.1
Mean receiver outlet temperature @ dp	905 °C	Sufficient to reach particle inlet temperature to the HX (900 °C)
Max. particle temperature	~1000 °C	Due to inhomogeneous temperature distribution
Receiver inlet temperature @ dp	605.5 °C	Derived from HX design
Receiver thermal power @ dp	96.23 MW_t	Per unit
Number of towers and receivers	6	
Solar multiple	2.5	Oversizing of solar field relative to power plant design point thermal demand
Thermal storage capacity	12 h	hours of discharging at full load

4.2 Methodology

The heliostat field layout was optimized by minimizing the estimated LCOE of the system. This requires three steps: (a) calculation of the annual thermal output of the receiver system, (b) determination of the capital and operational expenditure of the plant and, finally, (c) variation of parameters defining the number of heliostats in the field, their position and of the receiver system. All of these steps were done within the Visual HFLCAL software. While Steps (a) and (c) are part of the standard distribution of the software (Schwarzbözl, Pitz-Paal et al. 2009), cost and efficiency data for the TES system and power block had to be implemented as special routines.

The subsystem cost models are based on typical values for standard CSP systems (e.g., the heliostat field), DLR-internal assumptions for particle-related systems and the estimated cost for the chosen sCO_2 power block (see Deliverable 1.1 and Heller, Glos et al. in press). The chosen values are furthermore listed in Annex 1.

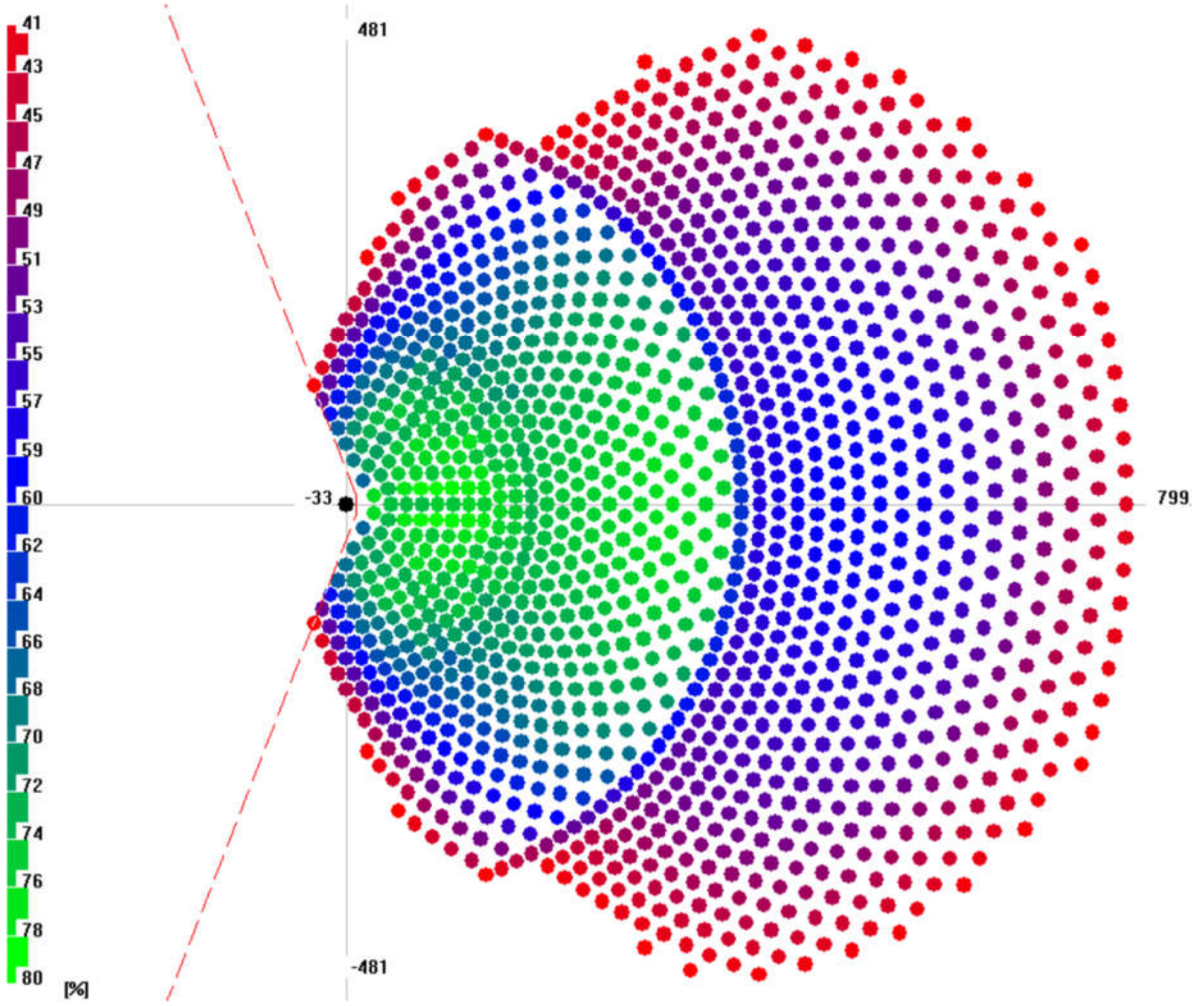


Figure 7: Heliostat field layout showing average annual efficiency per heliostat (color code)

4.3 Optimization Results

The heliostat field layout with the minimum levelized cost of electricity (LCOE) as derived by HFLCAL is depicted in Figure 7. The major results are presented in Table 4 and further details are given in Annex 1. These results are in the expected range for a large cavity receiver system. The very high flux at the aperture of the receiver leads to a high thermal efficiency (considering the high outlet temperature) while the optical efficiency of the field is penalized.

Table 4: Main results of field optimization (dp: design point)

Parameter	Unit	Value
Height of receiver center above ground	[m]	133.6
Receiver aperture diameter	[m]	7.58
Mean solar flux at receiver aperture @ dp	[MW/m^2]	2.38
Heliostat aperture area (per tower)	[m^2]	170 000
Particle inventory (per tower)	[t]	5172
Field efficiency @ dp	[-]	63.6 %
Field efficiency, annual average	[-]	54.2 %
Receiver efficiency @ dp	[-]	89.7 %
Receiver efficiency, annual average	[-]	87.4 %

The required particle inventory is determined by the thermal demand of the power block, the storage size and the temperature spread between hot and cold tank. Due to the high temperature of the sCO_2 at the inlet to the heat exchanger (~550 °C), this spread is only approximately 300 K in the investigated setup, leading in turn to a rather large particle inventory.

4.4 Additional Relevant Parameters

Some additional parameters, which don't follow directly from the heliostat field and receiver layout, could provide valuable information for material considerations. These are given in the following.

4.4.1 Solar Flux

The mean solar flux on the receiver aperture for the defined design is given in Table 3. The flux distribution on the particles on the receiver inner wall could be calculated for each time step/sun position via raytracing. However, as currently it is not foreseen that this data will be needed for the development tasks in the COMPASsCO2 Project, these raytracing simulations were not conducted at this point in time. In case this detailed information is needed, it can be provided upon request.

4.4.2 Thermal Shock During Cloud Transients or Shut Down

As part of the CENTREC500 project, in which a 500 kW_t receiver with an aperture diameter of 1.13 m was developed, the temperature drop at defocus was investigated. Figure 8 shows the measured temperatures in the receiver. The heliostat field was automatically defocused at a certain time and a temperature drop of around 20 °C/min was observed.

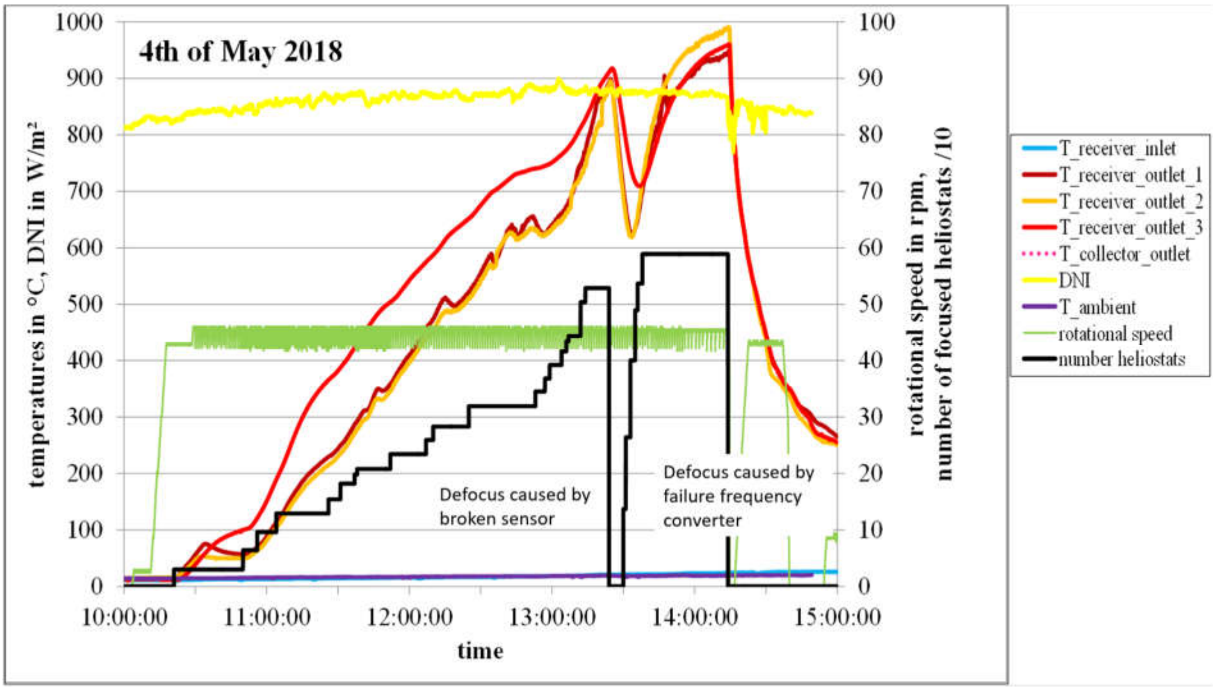


Figure 8 Temperature measurements in Centrec500 receiver

In addition, other projects, such as the HIFLEX project, and doctoral theses are being undertaken to investigate the behavior of the receiver in a transient state. More information about the transient behavior of the receiver will be provided later. For the scope of

COMPASsCO2 this effect seems not to be very relevant, as the large storage tank allows to near steady conditions at the PHX inlet on the particle side. For the particles themselves, it is to be investigated if strong temperature gradients at the receiver may affect them.

4.4.3 Particle Velocities in the Receiver

The velocity profile of the particles in the receiver depends on the thickness of the particle film. Numerical and experimental investigations have already been carried out in a small prototype for this purpose. For this investigation Bauxite particles from the company Saint Gobain with 1.2 mm Sauter diameter (mesh size 16/13) are employed. The rotational speed and inlet particle mass flow rate are 150 rpm and 25 g/s, respectively. Figure 9 shows the velocity profile in the axial direction of 13.8 cm aperture diameter receiver. It can be seen that the velocity profile of the particles has roughly exponential behavior. It means that the layer absorbing the solar rays, which are mostly the first two layers, have less residence time, while the shaded layers, which are mostly heated by conduction and short-range radiation, move more slowly.

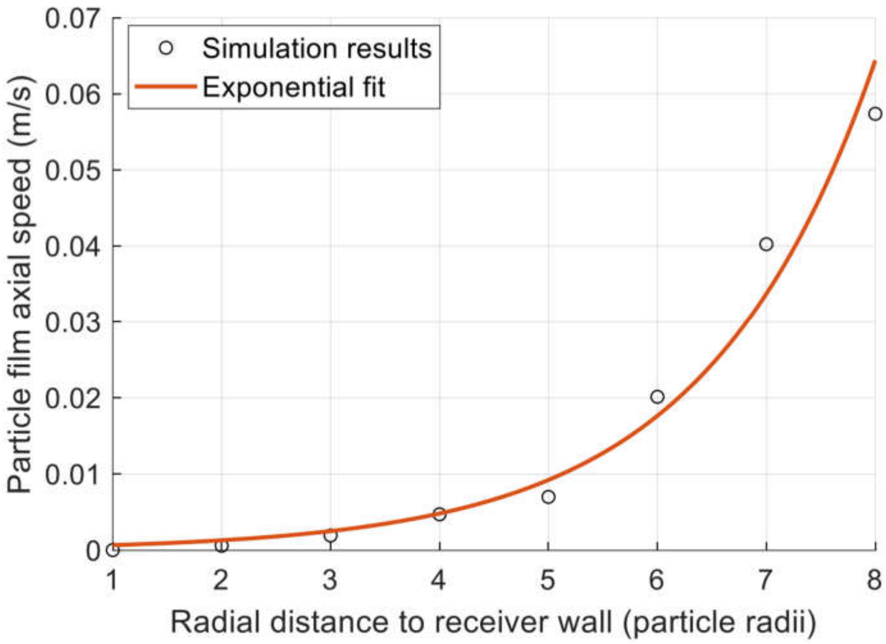


Figure 9 Velocity profile of particle film in radial direction

Due to the relatively high mass flow in COMPASsCO2, which is around 100 kg/s per receiver, the velocity profile shown above cannot be directly used because of the large difference in size. Since no experiences are available for such large mass flows, DLR is currently in the process of developing a model that determines the particle velocities for different mass flows as well as different rotation speeds. The model is estimated to be available in the middle of 2021, and only by then detailed information about the particle velocity can be provided.

4.4.4 Falling Distance from Receiver to Containment Vessel

The vertical distance between the receiver outlet and the containment vessel depends on specific tower designs. Furthermore, design measures to minimize the falling distance, e.g. by introducing inclined pipes, are conceivable. Therefore, a critical falling distance should rather be defined so that the necessity of and requirements on such measures can be evaluated.

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6 ANNEXES

6.1 Annex 1. HFLCAL Databook

No.	Item	Unit	Value	Comments
	Location			
1.	Location name	[]	Postmasburg, South Africa	Location of Redstone Solar Thermal Power Plant Project
2.	Latitude	[°] N	-28.298	According to meteo file
3.	Longitude	[°] E	23.366	
4.	Altitude	[m]	1514	
5.	Annual DNI	[kW h/ (m^2 year)]	2657	
	Design Points			
6.	Design point	[tt:mm - hh]	21.03. – solar noon	
7.	DNI design point	[W/m^2]	992	Calculated with clear sky model in HFLCAL
8.	Atmospheric transmittance	[]	Clear sky: $\eta_{atmo} = 0.99321 - 1.1176\text{E-}4 \cdot SLR + 1.97\text{E-}8 \cdot SLR^2$, for $SLR \leq 1000$ m. $\eta_{atmo} = e^{-1.106\text{E-}4 \cdot SLR}$, for $SLR > 1000$ m.	Standard clear sky model in HFLCAL. *SLR*: slant range
	Heliostat			
9.	Heliostat type/name	[]	Multi-facetted glass metal heliostat with 2-axes drive, pedestal mounted	Based on Abengoa Sanlúcar 120
10.	Net reflective area per heliostat	[m²]	121.34	
11.	Facet reflecting surface	[m²]	4.33	
12.	Aperture width	[m]	12.84	
13.	Aperture height	[m]	9.45	
14.	Height of Pylon	[m]	5.02	
15.	Number of facets	[-]	28 (4h x 7v)	
16.	Annual mean reflectivity	[%]	89.34	Product of reflectivity (94 %), mean cleanliness factor (96 %), and availability (99 %); (Giuliano, Puppe et al. 2017)
17.	Beam error	[mrad]	3.25	Sum for HFLCAL (slope error, tracking error, sun shape); (based on Balz, Göcke et al. 2016)
18.	Canting	[-]	On-axis	(Giuliano, Puppe et al. 2017)

No.	Item	Unit	Value	Comments
	Solar field – system definition			
19.	Field layout	[-]	Polar (Multi-tower)	
20.	Number of heliostats	[-]	1401	HFLCAL Optimization results
21.	Net field reflective area	[m²]	170 000	
22.	Optical efficiency of solar field @ DP	[%]	63.6	
23.	Optical efficiency of solar field annual	[%]	54.2	
	Solar tower			
24.	Type	[-]	Concrete	
25.	Number of towers	[-]	6	
26.	Solar multiple	[-]	2.5	
27.	Height of receiver center above ground	[m]	133.6	HFLCAL Optimization results
28.	Diameter	[m]	15	For shadow
	Solar receiver			
29.	Receiver type	[-]	CentRec©	
30.	Heat transfer medium (HTM)	[-]	Bauxite particles	
31.	Thermal power @DP	[MW_t]	96.23	
32.	Min/max thermal load	[%]	120 % / 10 %	
33.	HTM inlet temperature	[°C]	605.5	Input from D1.1
34.	HTM outlet temperature	[°C]	905	900 °C at PHX inlet
35.	Receiver model Parameter 1 Parameter 2 Parameter 3 Parameter 4	[] [-] [-] [-] [kW/(m² K)]	103 0.950 0.900 1.000 0.030	For field layout in HFLCAL: P1: Opt. Efficiency P2: Emissivity P3: Relative mean receiver temperature P4: Convective heat transfer coefficient

No.	Item	Unit	Value	Comments
36.	Aperture diameter	[m^2]	7.58	HFLCAL Optimization results
37.	Mean flux on receiver aperture @ DP	[MW_t/m^2]	2.38	
38.	Tilt angle	[°]	30.2	
39.	Receiver thermal efficiency @ DP	[%]	89.7	
40.	Receiver thermal efficiency annual	[%]	87.4	
	Power Block			
41.	Desing point net rating	[MW_e]	112.8	
42.	$T_{PHX,sCO2,out}$	[°C]	700	Project description
43.	$T_{PHX,sCO2,in}$	[°C]	558.1	Deliverable 1.1
44.	Power Block net efficiency	[%]	49.0	Partial cooling + RH cycle (Deliverable 1.1)
45.	Heat transfer coefficient Pa-PHX	[W/(m^2 K)]	300	Needed for PHX cost correlation (Buck and Giuliano 2018)
	HFLCAL Cost models			
46.	5-digit code	[]	812	HFLCAL cost model
47.	DNI factor	[-]	0.7529	Ratio of annual DNI (meteo) over annual clear sky DNI
48.	Heliostat field	[EUR/m^2]	110	Including land and preparation
49.	Tower	[EUR]	1 767 767 EUR $e^{0.006931\ ath/m}$	*ath*: height of receiver center above ground
50.	Receiver (structural)	[EUR/m^2]	70 000	Cost per aperture area

No.	Item	Unit	Value	Comments
51.	Receiver (insulation)	[EUR/m²]	1000 (1 + ($T_{Rec,out}$/K – 600)/400)	Cost per receiver insulated area (HFLCAL optimization result)
52.	Power block w/out PHX	[EUR/ $kW_{e,net}$]	1976	Including all indirect costs and contingencies for PB. Calculated with "sCO2euro_T_PHX" cost model in Deliverable 1.1.
53.	PHX	[EUR]	128122 * A_{HX}^0.66	Cost per heat transfer surface area (Buck and Giuliano 2018)
54.	Contingency	[%]	30	Estimate
55.	O & M	[%]	2.3	Annual O & M cost as fraction of CAPEX of heliostats, tower and receiver.
56.	Annuity	[%]	8.58	Discount: 7 %; Debt period: 25 a.