CFD Analysis of an Open Volumetric Air Receiver and Comparison with 10 kWth Solar Tests

SolarPACES

L. Alonso-Pardo[1] , D. Sanchez-Señoran[1] , M. Biencinto[1] , J. Fernandez[1] , F. Zaversky[2] , X. Randez[2] , A. Fuessel[3] , W. Pritzkow[4] , Antonio Avila-Marin[1]

[1] CIEMAT – Plataforma Solar de Almeria (PSA), Tabernas, Almeria, Spain. [2] CENER – Solar Energy & Storage, Sarriguren, Pamplona, Spain. [3] Fraunhofer Institute for Ceramic Technologies and Systems IKTS, Dresden, Germany. [4] Walter E.C. Pritzkow Spezialkeramik, Filderstadt, Germany

*Correspondence: Antonio Avila-Marin, antonio.avila@ciemat.es

1. Introduction

The design and optimization of Open Volumetric Air Receivers (OVARs) require detailed numerical modeling to complement experimental campaigns and improve performance predictions. This work presents a CFD study of the thermal behavior of ceramic foam absorbers coupled with a funnelling-cup, focusing on heat transfer efficiency under varying operating conditions. The modeling strategy builds on previously validated lab-scale work [1], is extended here to simulate an absorber-cup configuration under concentrated solar irradiation. The model is benchmarked against 10 kW_{th} experimental tests conducted at the Plataforma Solar de Almería (PSA) within the Horizon Europe ASTERIx-CAESar project (funded under GA101122231).

2. Experimental and Numerical Methodologies

The experimental setup includes a single ceramic foam absorber and cup integrated into a thermal air loop designed to replicate full-scale receiver operation. Ambient air is forced through the absorber by a blower, then flowing sequentially through the receiver pipe, air/water heat exchanger, and flow meter. The setup is placed at 50 mm behind the focal plane of PSA's SF60 solar furnace, where a shutter controls the incident solar flux. Each foam and cup was tested under three solar input levels and three target air temperatures. The foam used has a porosity of 0.85, cell diameter of 1470 μm, window diameter of 490 μm, and strut thickness of 210 μm, and the cup is made of composite N610-DF13-4500/FW12. Quasi-steady state periods were selected for numerical comparison.

A 3D CFD model of the absorber (120 mm x 120 mm aperture) and cup (60 mm outlet diameter) was developed in STAR-CCM+, replicating the experimental conditions. A continuum approach was used, including radiative transfer (Rosseland approximation), forced convection, and local thermal non-equilibrium (LTNE). Simulations were performed for solar fluxes between 360 and 630 kW/m². The numerical methodology includes:

1. Governing equations: Navier-Stokes, fluid/solid energy, turbulence and radiation.
2. Mesh sensitivity analysis to ensure numerical accuracy.
3. Boundary conditions: Inlet air mass flow, outlet pressure, and thermal losses.
4. Validation by direct comparison with experimental measurements.

3. Results

The validation of the model is based on three thermocouples located near the cup exit, positioned approximately in the same axial plane. The model integrates the experimentally measured solar flux profile (Fig. 1, left).

Fig. 1 center and right qualitatively shows the evolution of the solid and fluid temperatures, highlighting strong gradients within the absorber-cup system. Consequently, comparison is focused at the outlet, where temperature fields are more homogeneous.

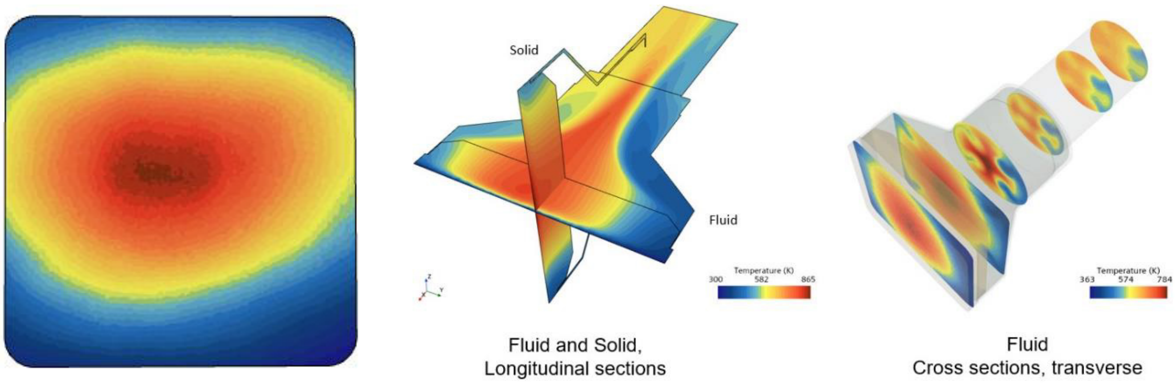

***Fig. 1**: Left – Solar flux profile; Center – Solid profile (N-S) and fluid profile (E-W); Right – Fluid sections within the absorber and cup*

Table 1 shows experimental temperatures of sensors TK4, TK5, and TK6, their average (TK456), and numerical predictions for a selected steady state period. Simulations were conducted using the average experimental mass flow rate $\dot{m}_{a,avr}$, with upper $\dot{m}_{a,max}$ and lower $\dot{m}_{a,min}$ bounds to assess deviations within the quasi-steady state period. The difference between the average experimental TK456 value and the average numerical result for $\dot{m}_{a,avr}$ is less than 2%. Moreover, numerical results also present the significant temperature variations within the given plane due to the solar flux profile and the mass flow variation, ranging from 478 K to 748 K. These values align well with the measurements from the three available thermocouples (TK4, TK5 and TK6).

***Table 1**. Comparison of cup outlet temperatures (in K): experimental sensors vs. numerical results*

	Experimental Data				**Numerical Data**		
	TK4	**TK5**	**TK6**	**TK456**	$T(\dot{m}_{a,avr})$	$T(\dot{m}_{a,max})$	$T(\dot{m}_{a,min})$
					13.7 g/s	14.1 g/s	13.1 g/s
Average	**524**	**652**	**624**	**600**	**610**	**601**	**621**
Maximum	532	658	632	607	735	724	748
Minimum	511	647	617	592	484	478	492

The thermal efficiency of the absorber-cup system was assessed using both experimental and numerical data. Based on the average experimental outlet temperature (600 K from T456), the efficiency is estimated at 83.1%. The corresponding numerical simulation, predicting 610 K, yields an efficiency of 85.7% confirming the model's reliability under the evaluated conditions. The same methodology was applied to simulate absorber-only performance, achieving 90.6% efficiency with an average outlet temperature of 627 K.

4. Outlook

The validated numerical model serves as a powerful tool inferring detailed insights about the system's behavior that would otherwise be challenging to obtain through experimentation. The full study will include an in-depth analysis of the absorber thermal efficiency under different operational scenarios, including solar flux and working temperatures. Future work will aim to simulate a full-scale receiver, align with the design and performance goals foreseen for implementation within the ASTERIx-CAESar project.

References

[1] Zaversky, F. et al. https://doi.org/10.1016/j.apenergy.2017.11.003