CFD Analysis of an Open Volumetric Air Receiver and Comparison with 10 kW$_{th}$ Solar Tests

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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], A. 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

Context:

ASTERIX CAESAR

ASTERIx-CAESar proposes a hybrid power plant consisting of a power tower system based on an open volumetric receiver and compressed air energy storage. The primary heat transfer fluid is **air** and the open volumetric receiver is made of **SiC ceramic foam**.

Aim of Pilot Plant:

- New operating strategy for power tower plants
- **Efficient & accessible materials for low operation cost** (1)
- Explore potential applications of residual heat

→→ CSP to an accessible and cost-effective option

Aim of study:

For optimal operation & yield of the plant, the properties of absorber, cup, and geometry of the receiver are studied in this work to increase the efficiency of this crucial component.

- Optimization of thermal efficiency → **improves** (1)
- Validation of 3D CFD model → **For potential use in a simulation of the full receiver.**
- Characterization of thermal & fluid dynamic effective properties of component → **for implementation in full plant model**

+ Comparison of proposed materials – Proprietary ceramic production recipe and design.

Methodology:

Operation & Simulation Conditions:			
Absorber Outlet Temp. & corresponding mFR	Solar furnace shutter aperture & Corresponding Solar Heat Flux		
600 °C	20 %	25 %	30 % Shutter
11-19 g/s	5.2 kW$_{th}$	7.1 kW$_{th}$	8.8 kW$_{th}$

x 7 Foam Samples

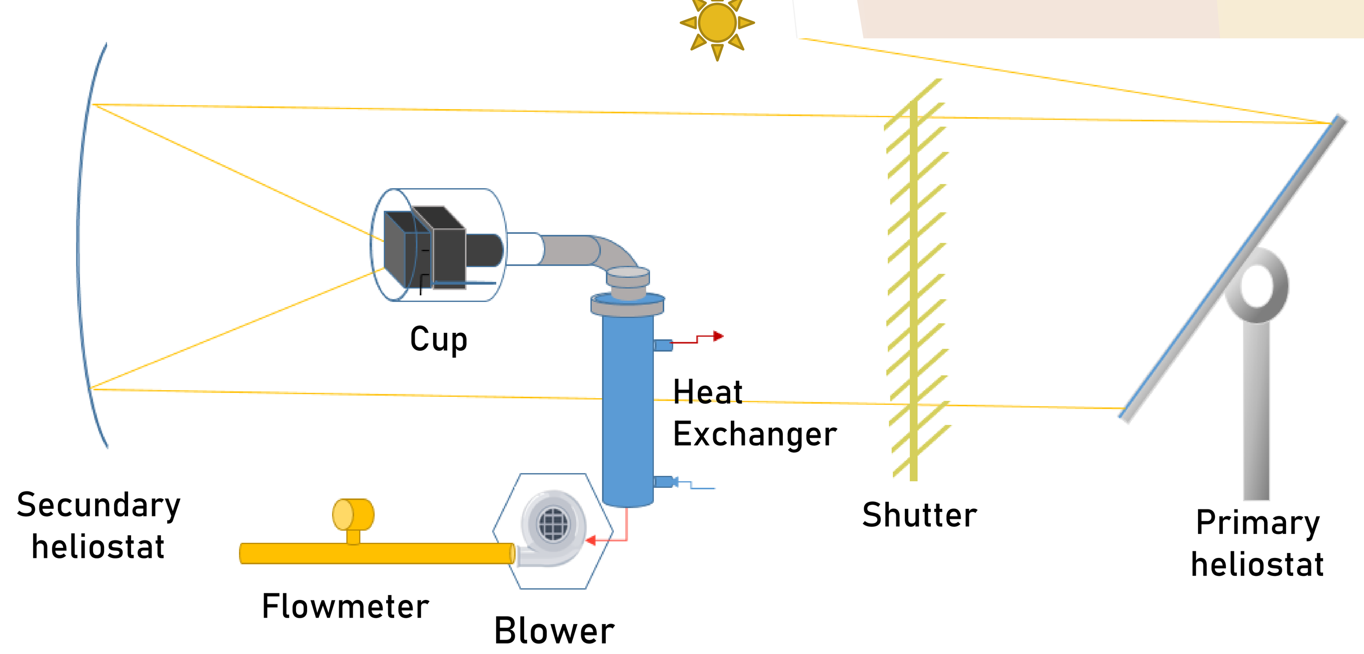
Experimental:

- Operation conditions:
  - Mass Flow Rate (mFR) adjusted with blower
  - Incident Flux adjusted with shutter
- Resulting measures for abs. module heat flux:
  - air temperature (thermocouples)
  - mFR (heat exchanger)

Numerical:

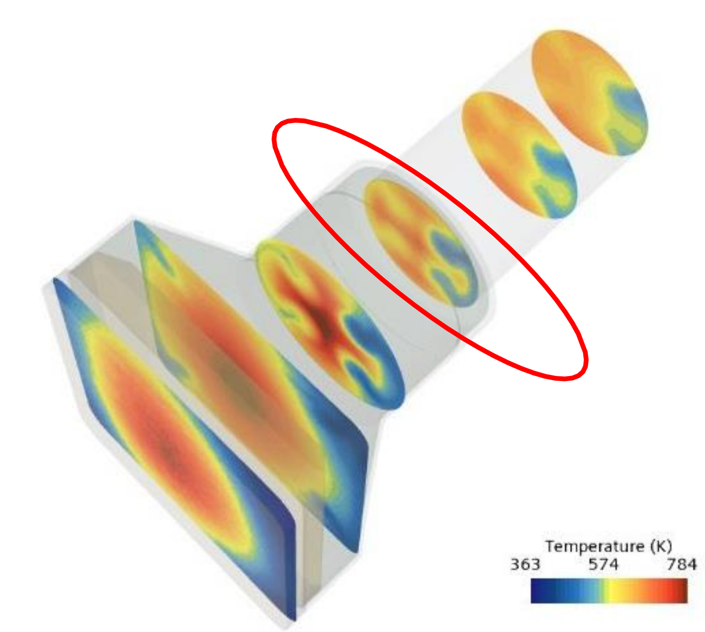
- RANS
- Quasi-Static
- Homogenous model
- LTNE

Experimental setup: Solar furnace bench test



3D CAD+CFD Model:

Boundary conditions:
- mFR
- Flux Map
- Ref. Pressure
- Ref. Amb temp
- Material properties (foam and cup)

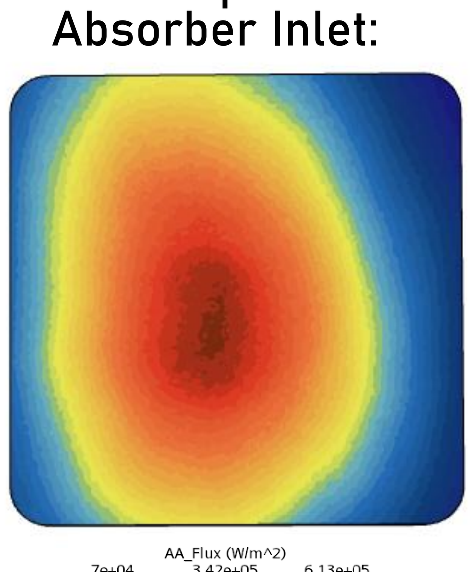


Fluid
Cross sections, transverse

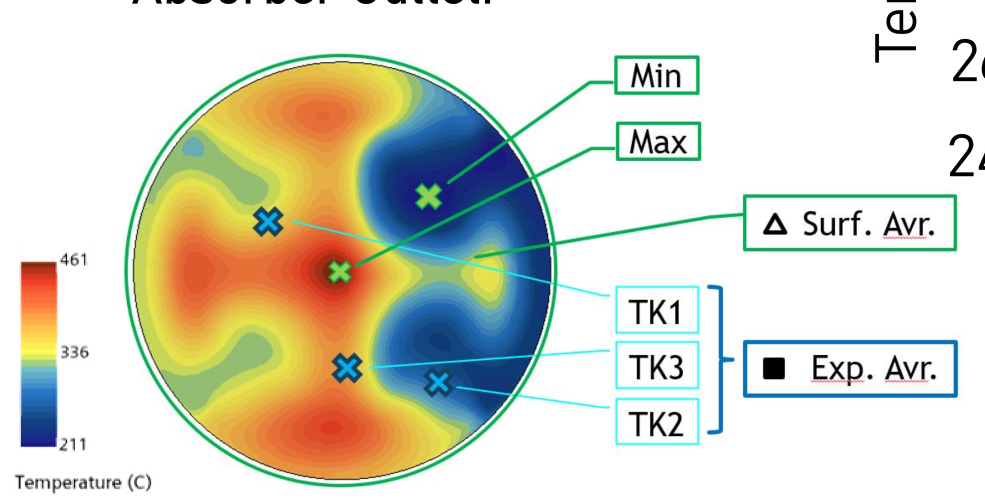
Results:

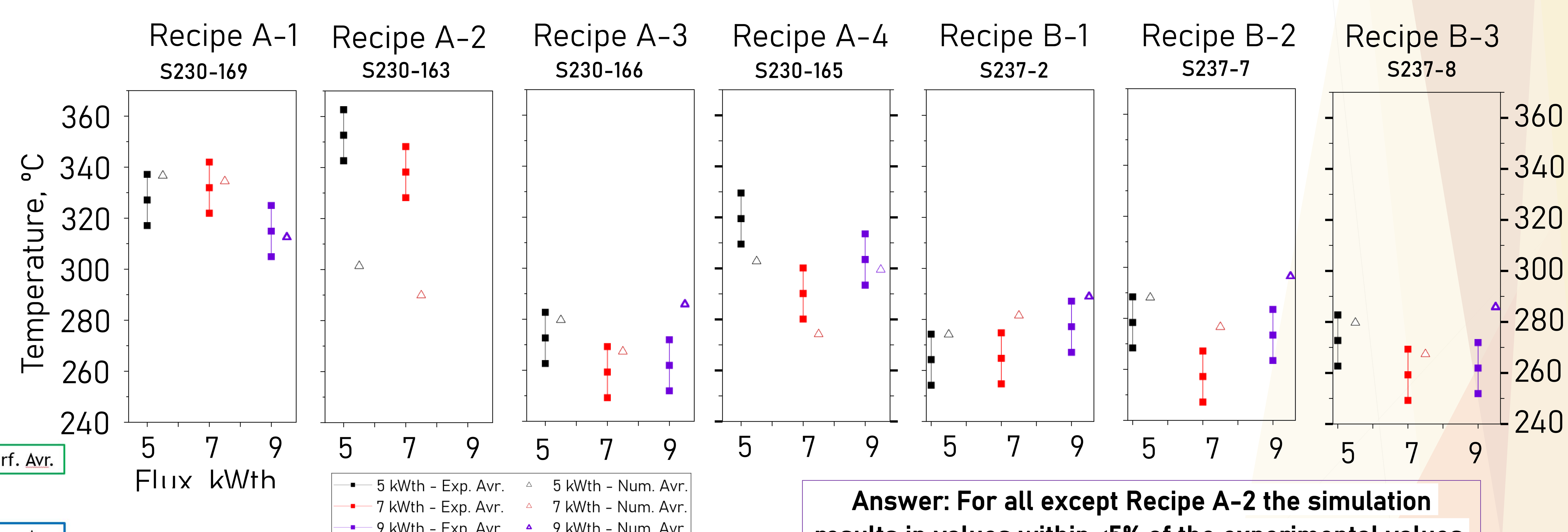
- Comparison between experimental and numerical values air temperature at the cup outlet.
- Question: **Are the numerical values within the range of experimental data?**

Flux Map at the Absorber Inlet:



Air temp at the Absorber Outlet:





Answer: For all except Recipe A-2 the simulation results in values within <5% of the experimental values.

Summary of the CFD Model:

- Simulation valid for:
  - Porosity 84% - 89%
  - mFR 13.4 g/s – 28.5 g/s
  - Flux 5.0 kWth – 9.0 kWth
- Capabilities of model:
  - 2D Flux map implementation
  - 3D fluid thermal and dynamic development
  - Heat Flux calculation → Future works: Thermal efficiency calc.
  - Pressure drop→ Future works: Blower Energy consumption calc.

Conclusions/Outlook :

- A **3D CFD** numerical model for 5-9 kW$_{th}$ conditions was built and validated.
- According to the model, for 600 °C at the absorber outlet, A-2 and B-3 have the **best thermal efficiencies** for each recipe type, those being 86.3% and 86.7% respectively, both for 7 kWth.
- New tests of best absorbers will be done on further outlet air temperature operation conditions.

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