Ceramic Foam Absorber Modeling and Optimization - Model Benchmarking and Validation Against Experimental Data

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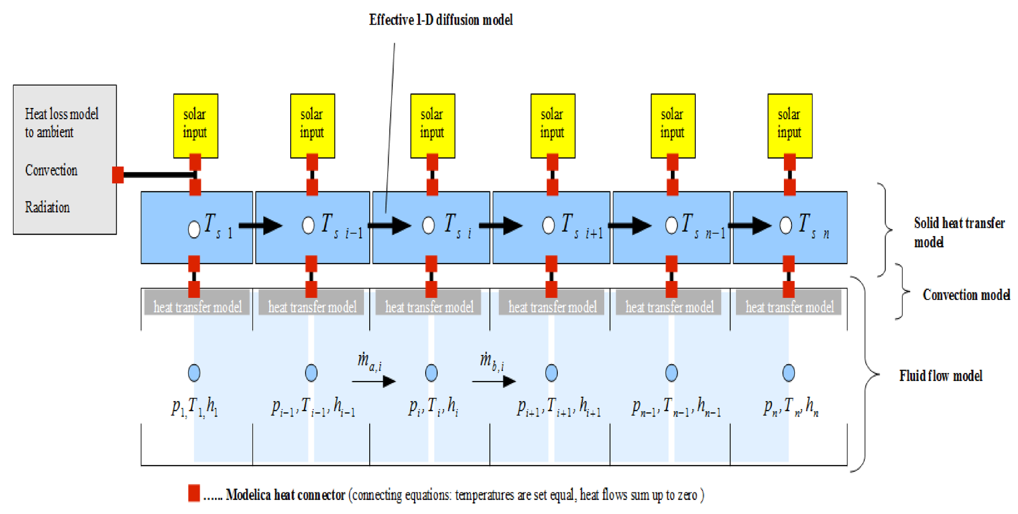
INTRODUCTION

The CAPTure (Competitive SolAr Power Towers - http://capture-solar-energy.eu/) project resumes the investigation regarding ceramic foam as solar absorber material. This research project will develop a prototype of a solar-driven hot air turbine powered by an open volumetric solar receiver. As volumetric solar absorber material, SSiC (pressureless sintered Silicon Carbide) foam is being studied. In order to reach highest possible solar absorber efficiencies, numerical models have been developed by CENER, CIEMAT-PSA and Fraunhofer-IKTS. The developed models have been benchmarked defining 3 references cases. Furthermore, the models have been run performing a large number of parameter variations, optimizing the receiver for thermal efficiency. Finally, the simulations have been validated by experimental data; small (40mm diameter) foam samples were tested in a 4KW solar simulator.

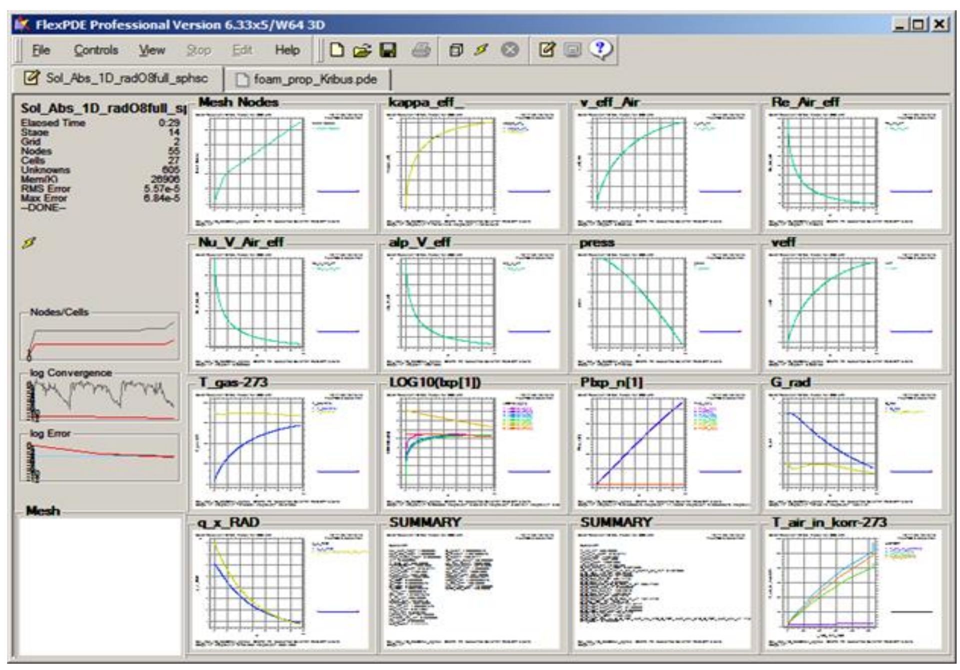
MODEL DESCRIPTION

1-D LNTE SOLAR ABSORBER MODEL (CENER)



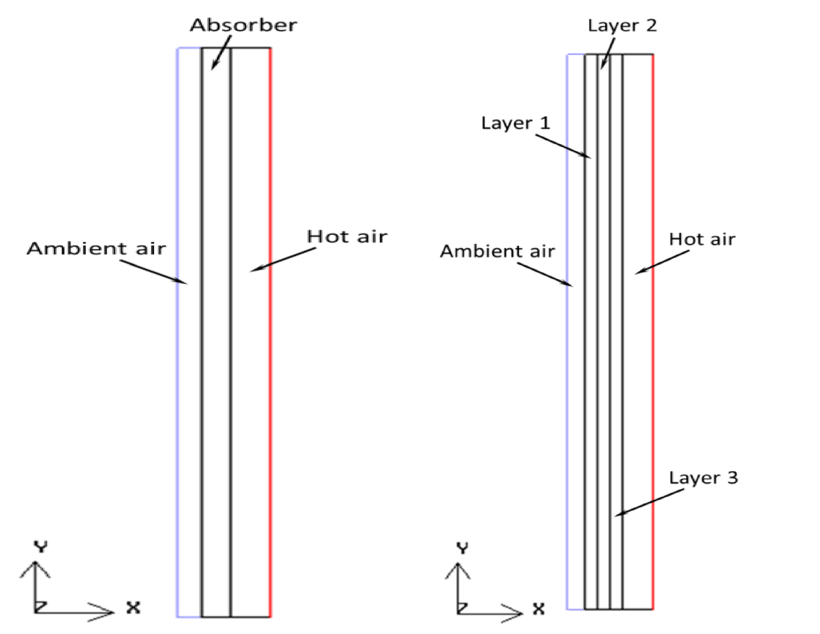
- Modelica language, Dymola
- Simplified radiation model
- One layer and multilayer structure

1-D LNTE SOLAR ABSORBER MODEL (IKTS)



- FlexPDE
- Simplified and 1-D Discrete Ordinates (DO) radiation model
- One layer and multilayer structure

2-D LTE ABSORBER MODEL (PSA-CIEMAT)

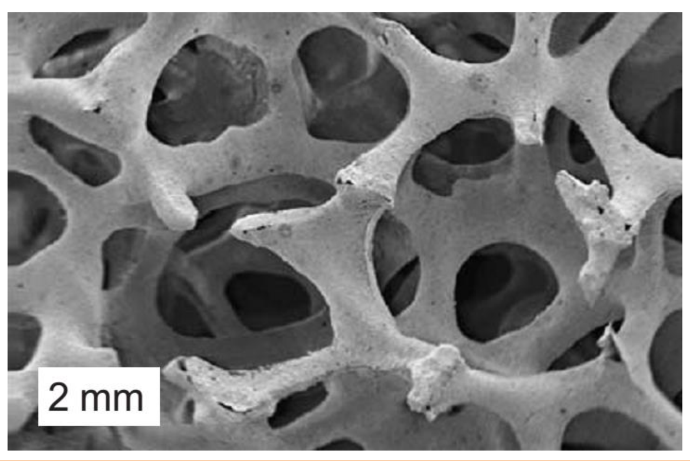


- Fluent
- One layer and multilayer structure

EXPERIMENT DESCRIPTION

Small foam absorber samples with 40 mm in diameter have been prepared by IKTS. Varied parameters are nominal cell density, porosity and sample thickness. Sample data for 7 cases are tested. Cases 1 to 4 are single-layer configurations. Cases 6 and 7 are double-layer configurations. Case 5 is a triple-layer configuration.

FOAM DETAILED VIEW

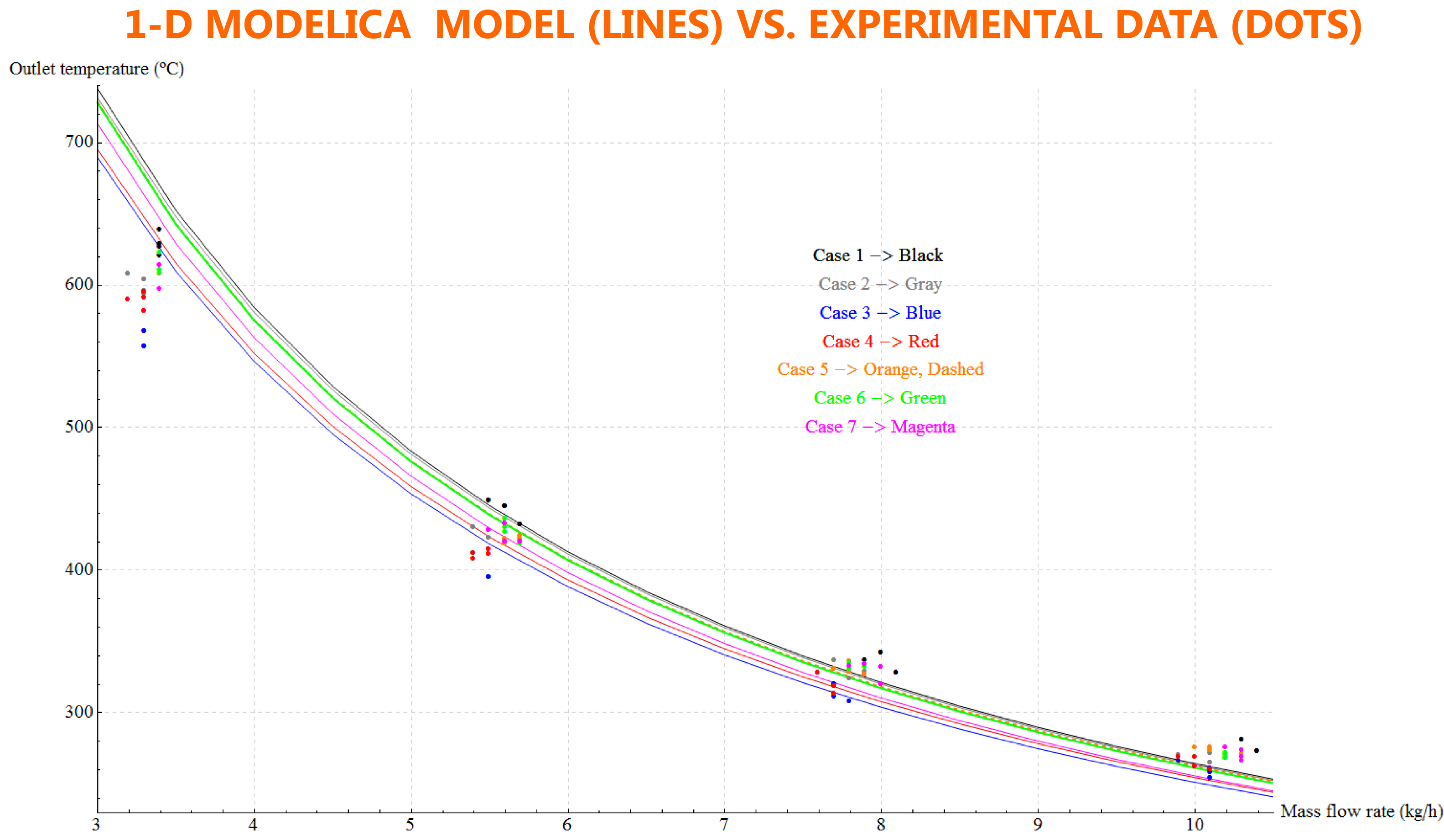


SOLAR SIMULATOR AT PSA-CIEMAT

RESULTS

In order to check the developed models for consistency, three different cases have been defined and simulated with the different models : CENER 1-D LNTE Modelica model with simplified radiation, 1-D LNTE IKTS FlexPDE model with discrete ordinates and simplified radiation model and PSA-CIEMAT 2-D LTE Fluent model. Furthermore, 7 cases are tested experimentally and the results obtained are compared with the 1-D Modelica model developed by CENER (right figure).

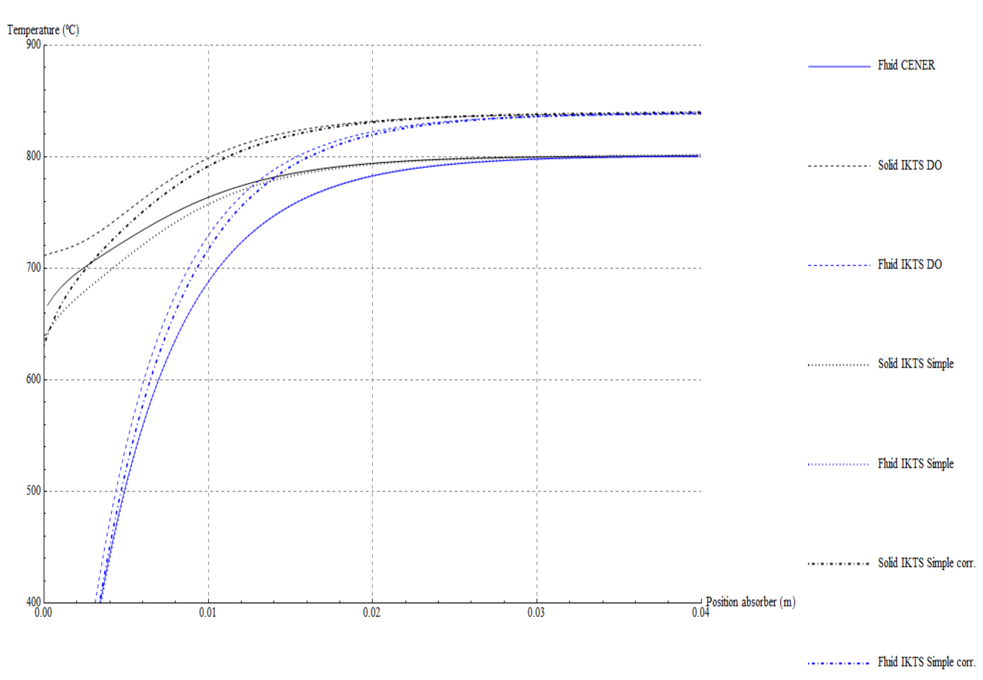
1-D MODELICA MODEL (LINES) VS. EXPERIMENTAL DATA (DOTS)



MODEL BENCHMARKING

Two of the three reference cases are single layer configurations with different levels of porosity, 0.87 and 0.75 (Run 1 and Run 2). The third configuration is a triple-layer foam with decreasing levels of porosity: 0.91, 0.85 and 0.81 (Run 3)

Parameter	Model	Run 1	Run 2	Run 3
Air outlet temperature (°C)	CENER	800	771	811
Thermal efficiency (-)	CENER	0.832	0.798	0.844
Air outlet temperature (°C)	IKTS DO model	838	821	844
Thermal efficiency (-)	IKTS DO model	0.877	0.857	0.883
Air outlet temperature (°C)	IKTS simplified	801	776	811
Thermal efficiency (-)	IKTS simplified	0.834	0.805	0.845
Air outlet temperature (°C)	PSA-CIEMAT	779	768	786
Thermal efficiency (-)	PSA-CIEMAT	0.847	0.834	0.854
Maximum absolute difference (°C) -		59	53	58
Maximum relative difference (%) based on minimum temperature increment across absorber-		7.8	7.1	7.6



Case	Cell density (PPI)	Open porosity (-)	Sample thickness (mm)	Cell diameter (µm)	Strut thickness (µm)	Incident power (W)
1	30	0.809	15	1419	285	760
2	30	0.777	15	1365	303	760
3	10	0.813	15	4200	784	760
4	10	0.79	15	4069	881	760
5 Layer 1	10	0.84	5	4226	746	760
5 Layer 2	20	0.809	5	2665	486	
5 Layer 3	30	0.741	5	1361	310	
6 Layer 1	10	0.84	5	4226	746	760
6 Layer 2	30	0.76	10	1344	301	
7 Layer 1	10	0.833	10	5403	765	760
7 Layer 2	30	0.741	5	1361	310	

CONCLUSIONS

- The different models confirm trends in terms of efficiency and outlet temperature very well.
- According to the parametric simulations, no gain in thermal efficiency can be obtained by a multi-layer configuration. Being the single-layer configuration also the thinnest option (low pressure drop), it is the preferred choice, simply due to simplicity of design.
- Good agreement is observed between model results and experimental data. The best performance is obtained by Case 1, a single-layer configuration, which has an open porosity of 0.809 and a nominal cell density of 30ppi. The multi-layer configurations stay clearly below this single-layer benchmark.

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