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Chemical Process and Energy Resources Institute / Centre for Research & Technology Hellas

Full-scale Simulations of a CFB Power Plant Reactor

***Webinar**:*

Accelerating Energy Sector Decarbonization through Waste-Derived Fuels and CCS Technology

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REBECCA

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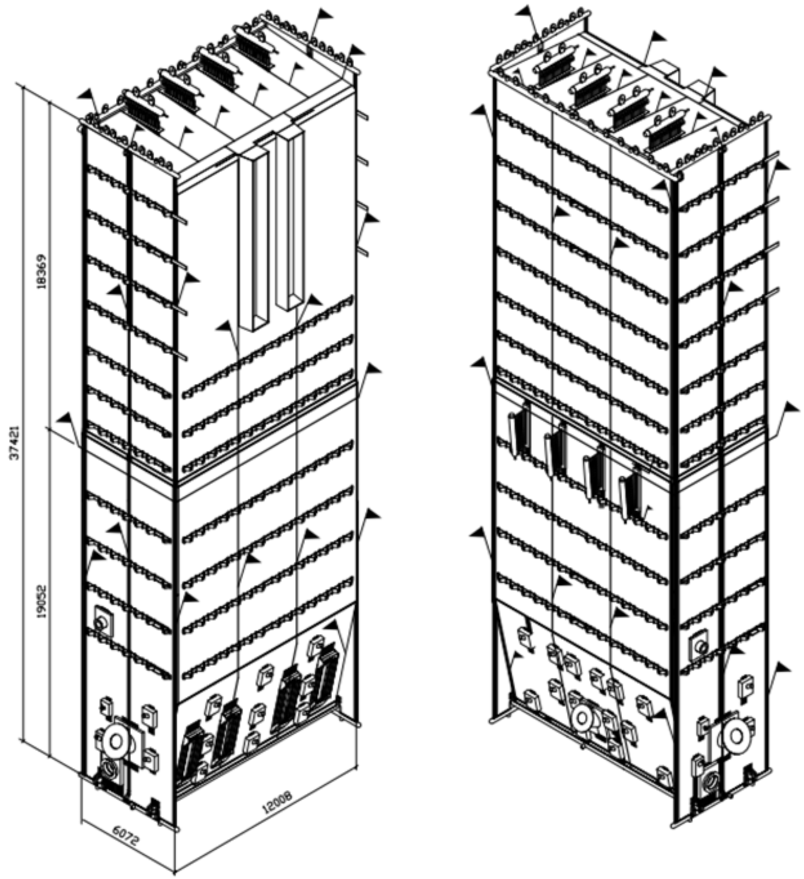
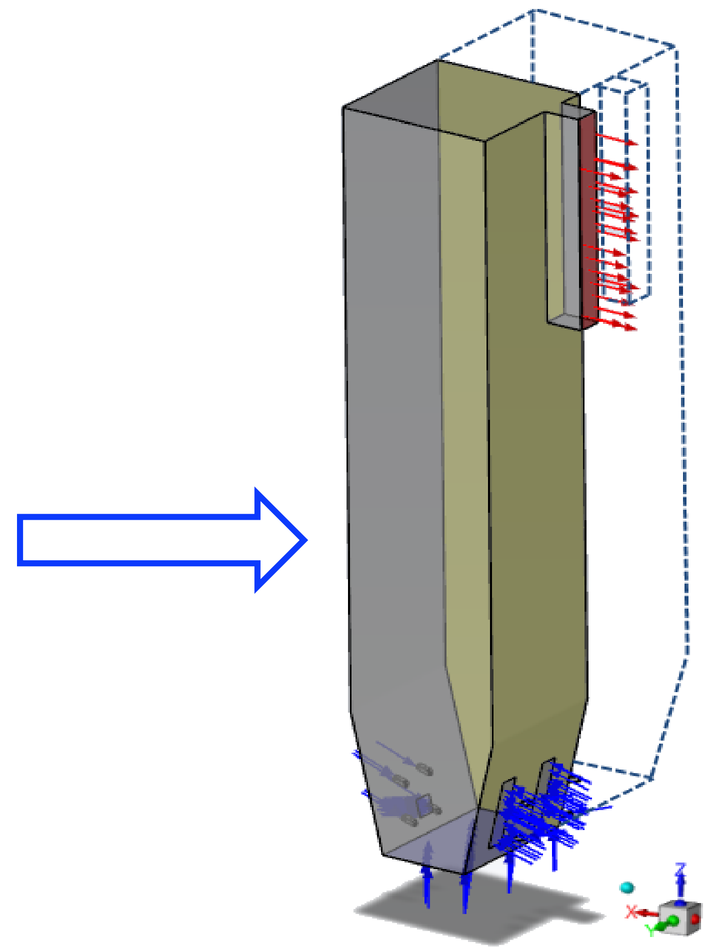
CFB boiler Geometry

CFD Simulation of two full-scale fluidized bed boilers

1) **Co-combustion reactor**
2) **Air reactor**



Furnace Design



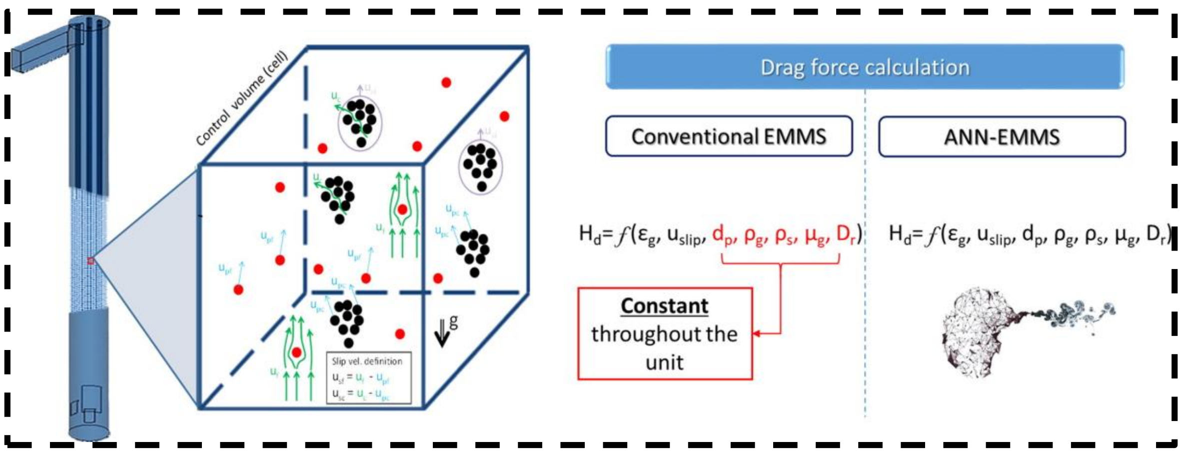
CFD Model

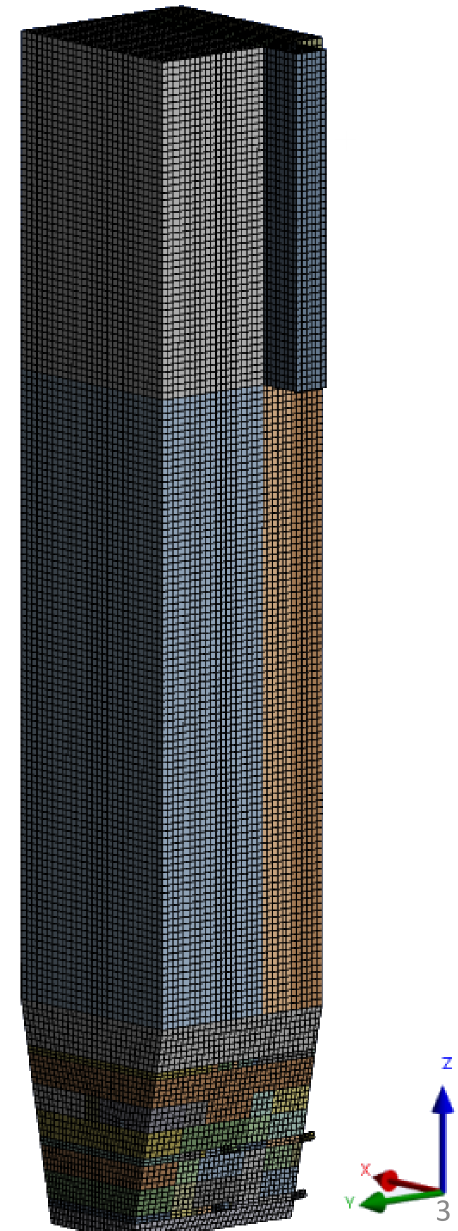
In order to reduce the computational cost, the symmetric geometry of the CFB boiler allows us to simulate half of the reactor by assuming symmetry boundary condition.

Numerical Grid & Drag Model

The grid with **259,322** number of elements was used. Grid independency study provides an acceptable low average percentage error 14.74% against exp. pressure profile data.

Drag model: **ANN-EMMS**[1] (**Certh's code**) provides the lowest average error rate (**15.23%**), against experimental pressure profile data, compared to **Gidaspow** and **EMMS Fluent model**.

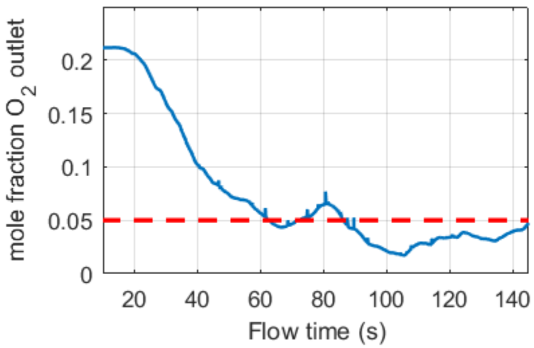


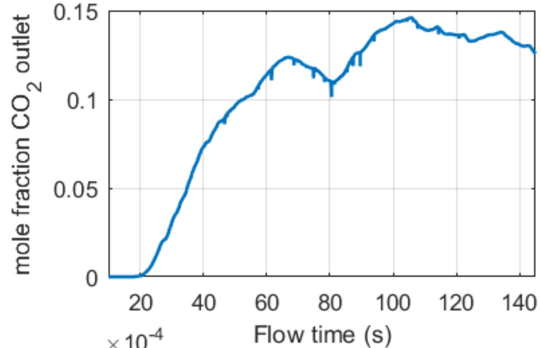


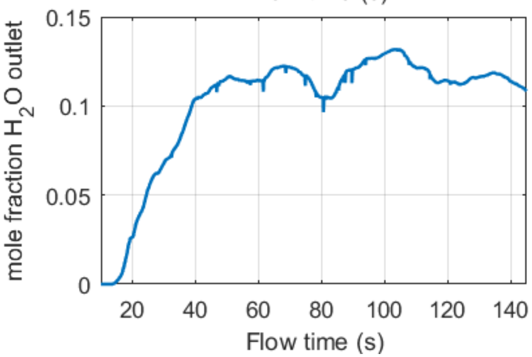
[1]*Stamatopoulos P, Stefanitsis D, Zeneli M, Nikolopoulos N. Development of an artificial neural network EMMS drag model for the simulation of fluidized beds in chemical looping combustion. Chemical Engineering Science. 2023 Dec 5;282:119286.*

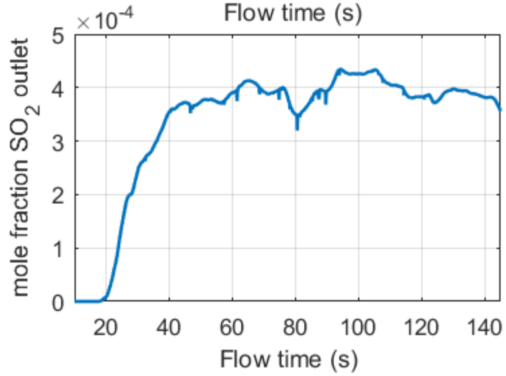
Operation of Co-combustion reactor

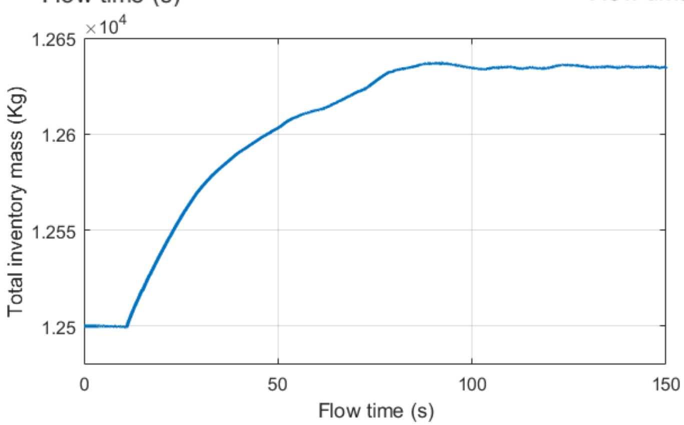
Total flow time: 150s (<u>1sec Simulation Flow time ~ 10h</u>)
"Pseudo-steady-state": 100s-150s

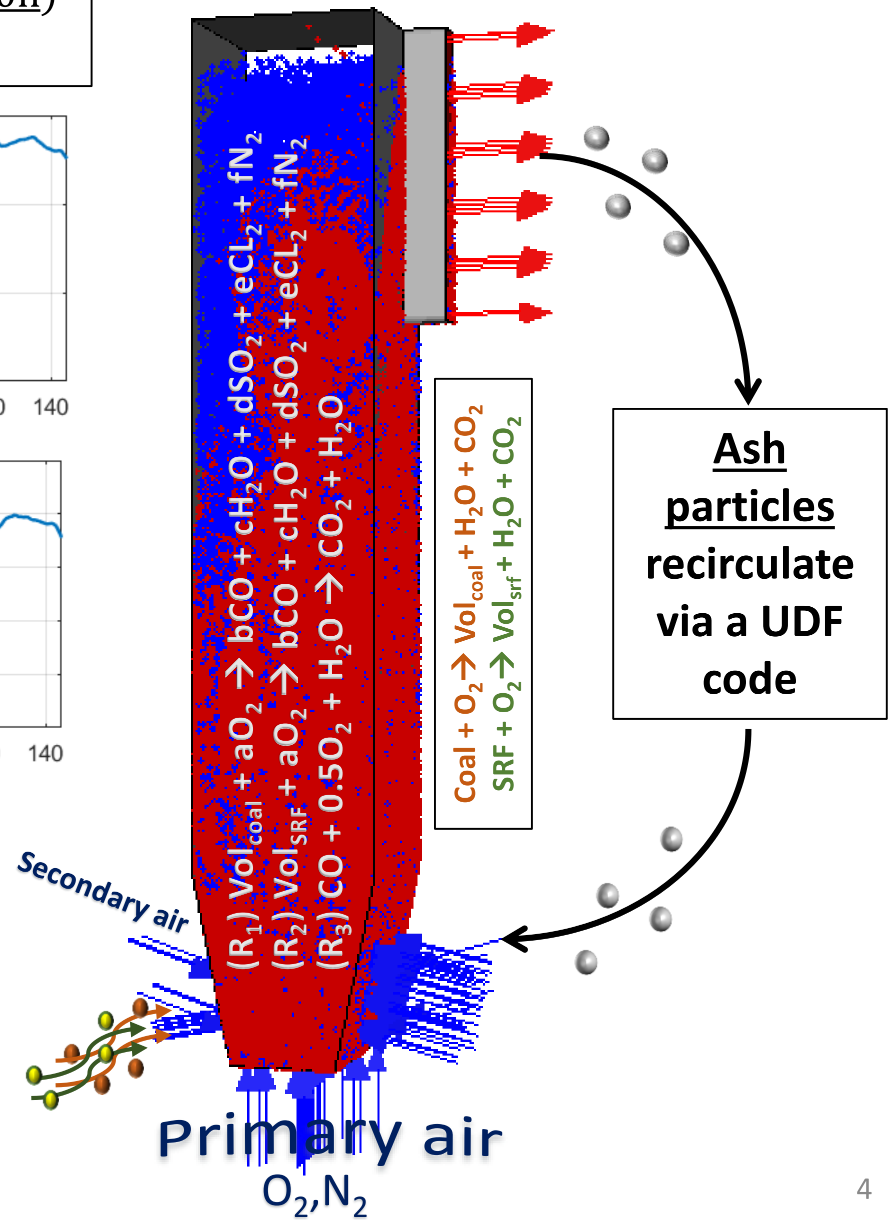








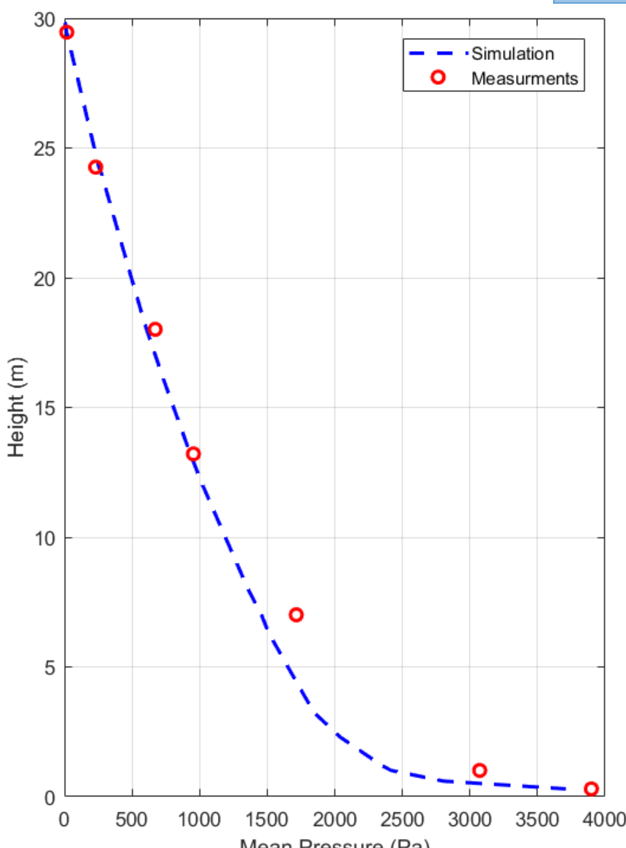


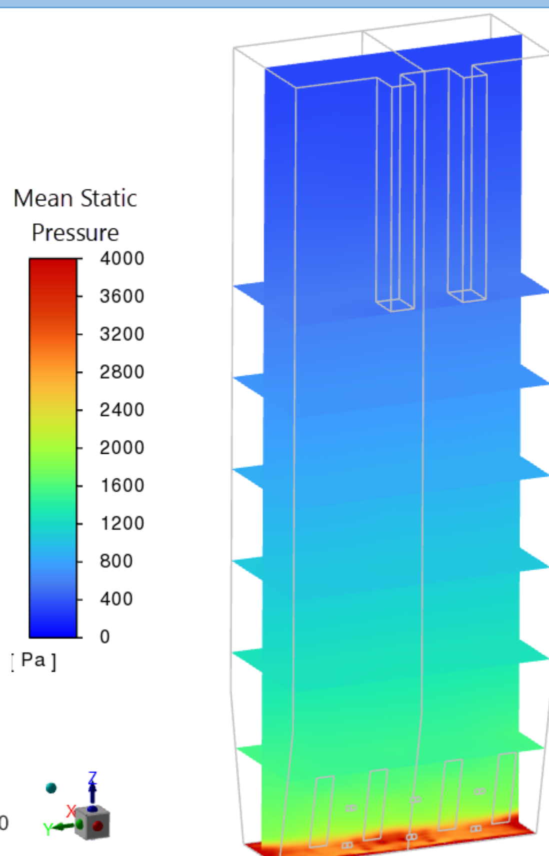


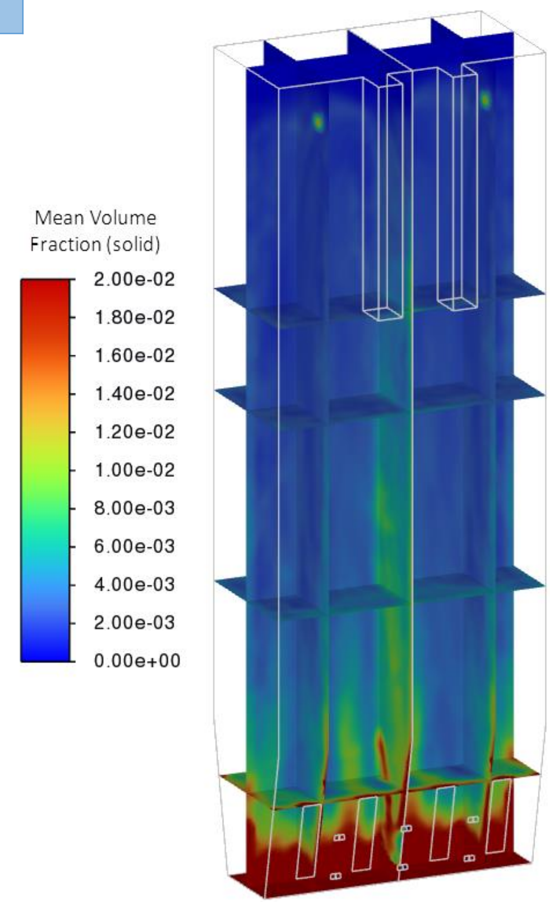
Results
Co-combustion reactor

Pressure profile

Mean Pressure [Pa]			
Height(m)	**Measurements**	**Simulation**	**Error**
29.46	17.5	16.37	6.5%
24.26	231.33	255.12	10.3%
18.01	671.68	607.21	9.6%
13.21	954.35	931.43	2.4%
7.01	1715.24	1457.45	15.0%
1.01	3072.1	2417.09	21.3%
	AVERAGE		**10.8%**







Results

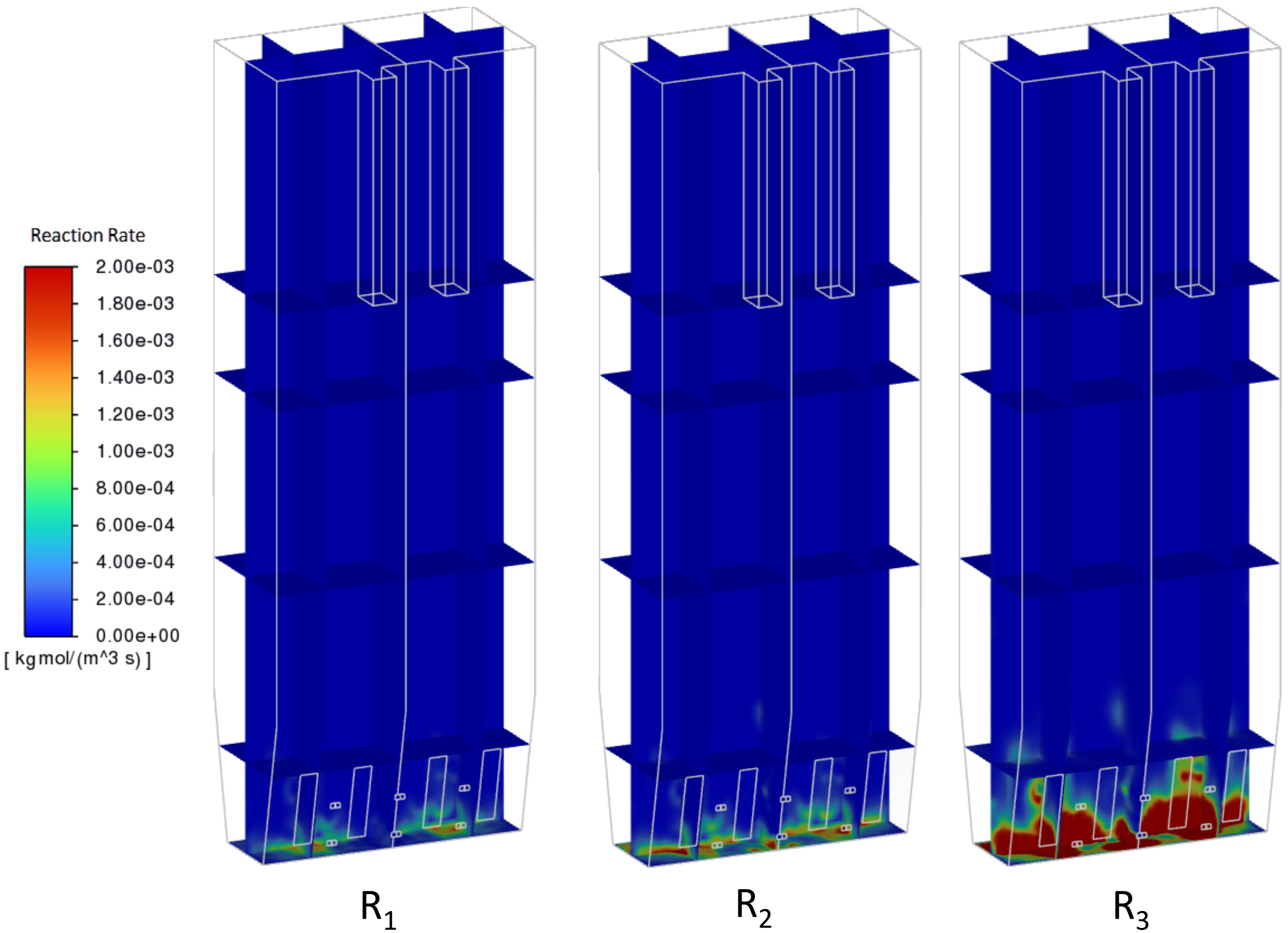
Co-combustion reactor

Reaction Rates

(R$_1$) $Vol_{coal} + O_2 \rightarrow CO + H_2O + SO_2 + CL_2 + N_2$

(R$_2$) $Vol_{SRF} + O_2 \rightarrow CO + H_2O + SO_2 + CL_2 + N_2$

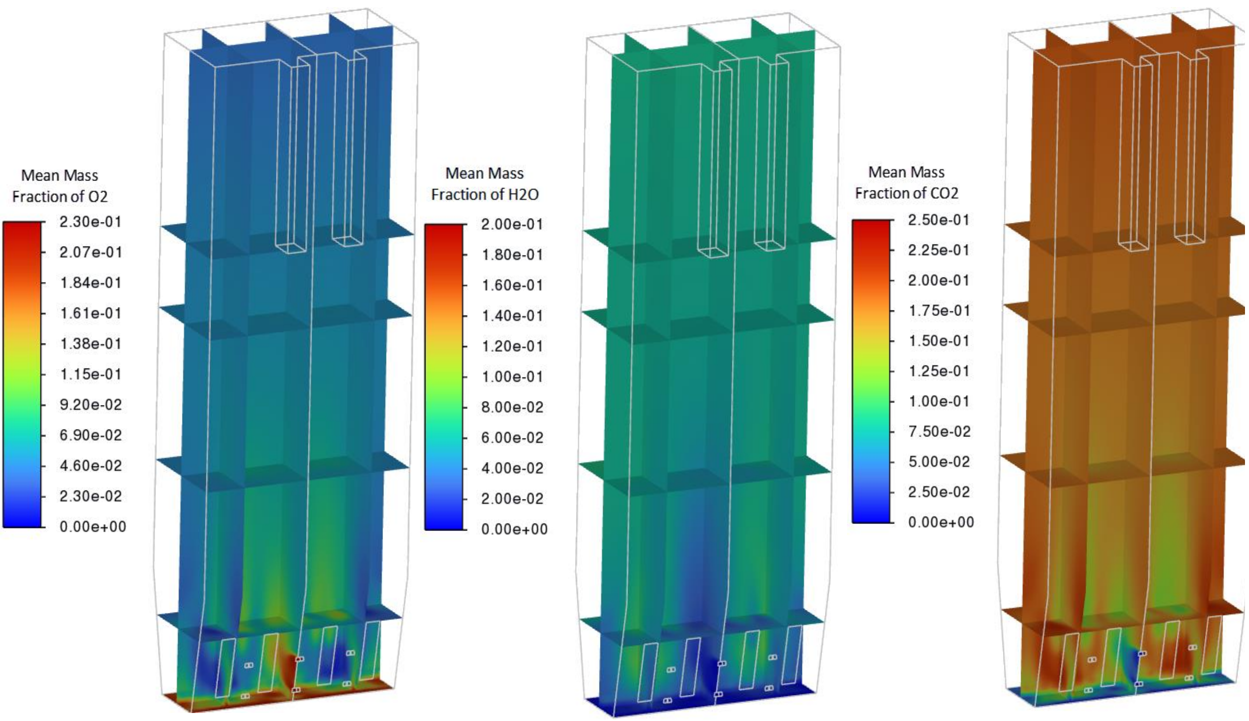
(R$_3$) $CO + 0.5O_2 + H_2O \rightarrow CO_2 + H_2O$

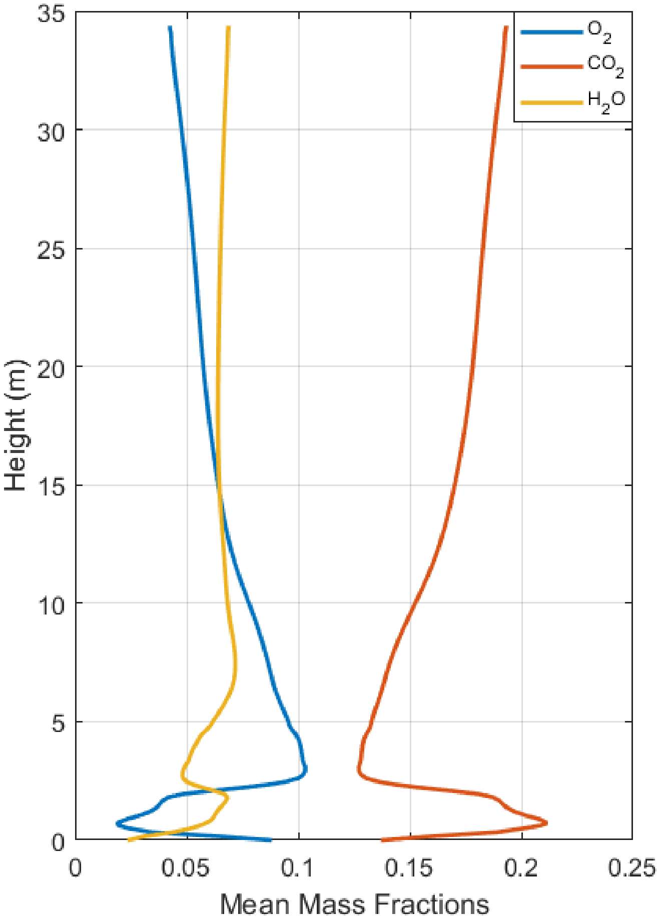


Results

Co-combustion reactor

Species Concentrations of
O_2, H_2O, CO_2



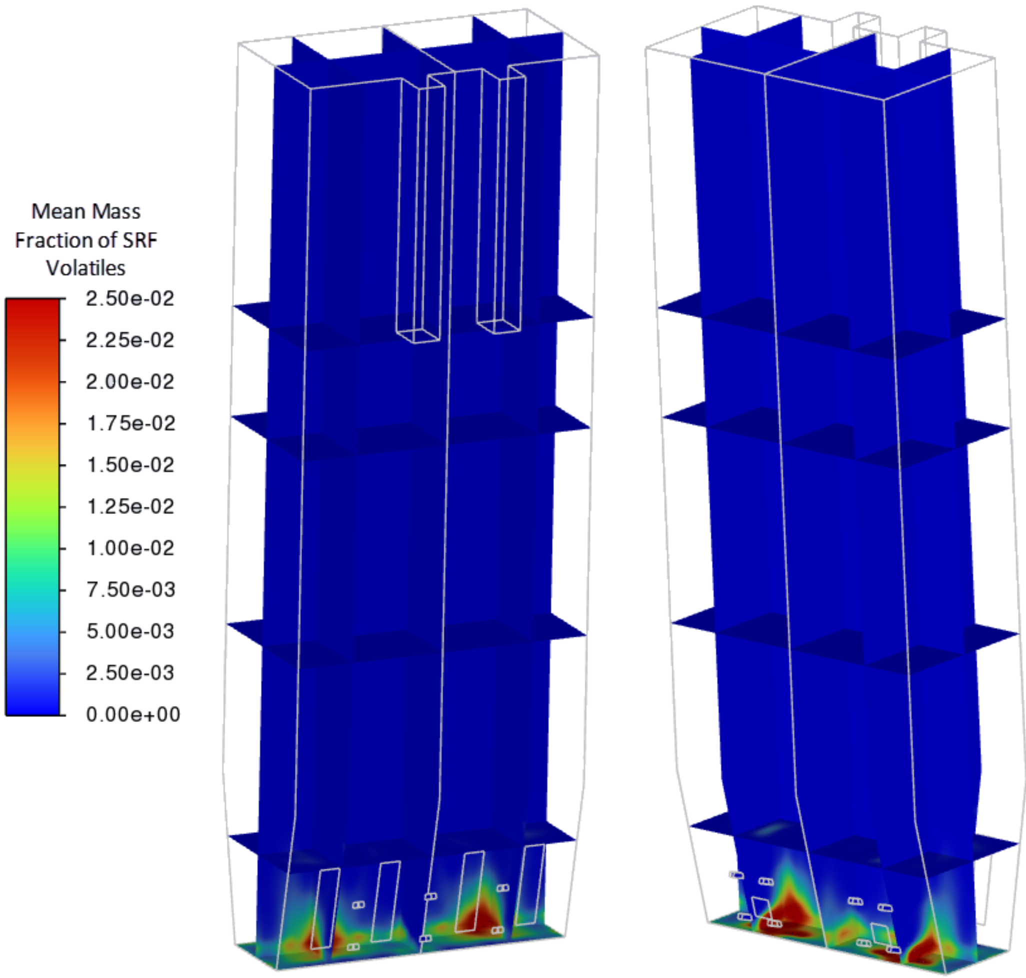


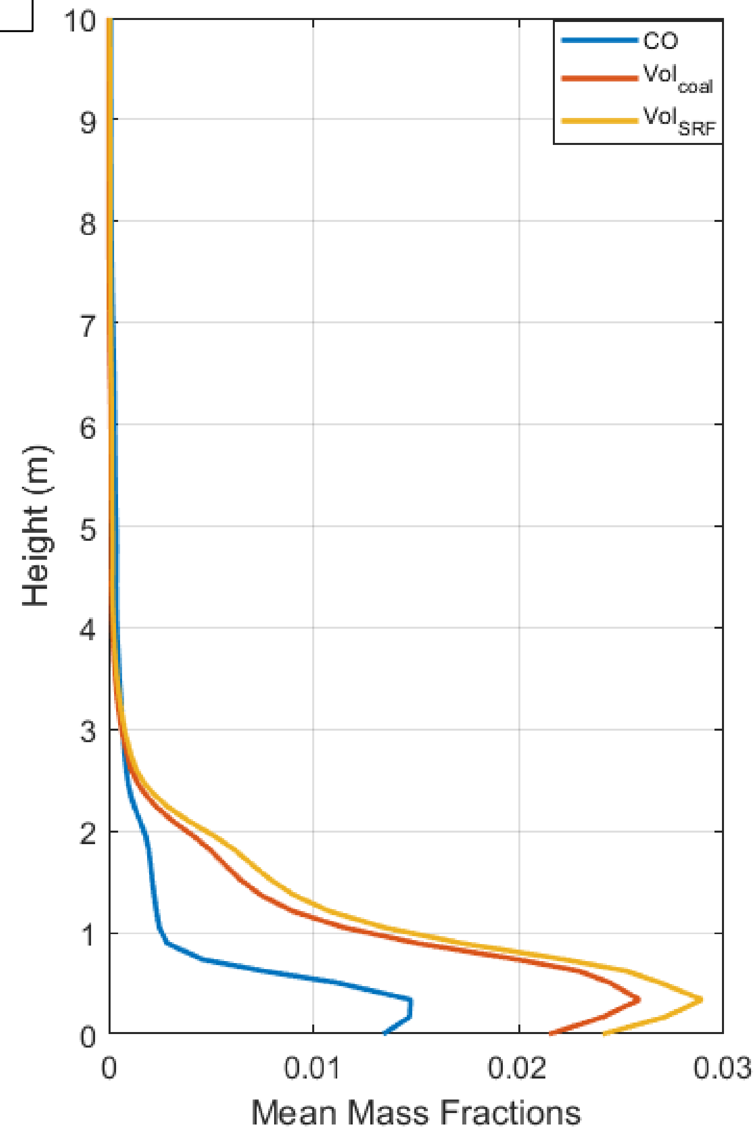
$$Coal + O_2 \rightarrow Vol_{coal} + H_2O + CO_2$$
$$SRF + O_2 \rightarrow Vol_{srf} + H_2O + CO_2$$

Results

Co-combustion reactor

Species Concentrations Volatiles of CO, SRF and Coal



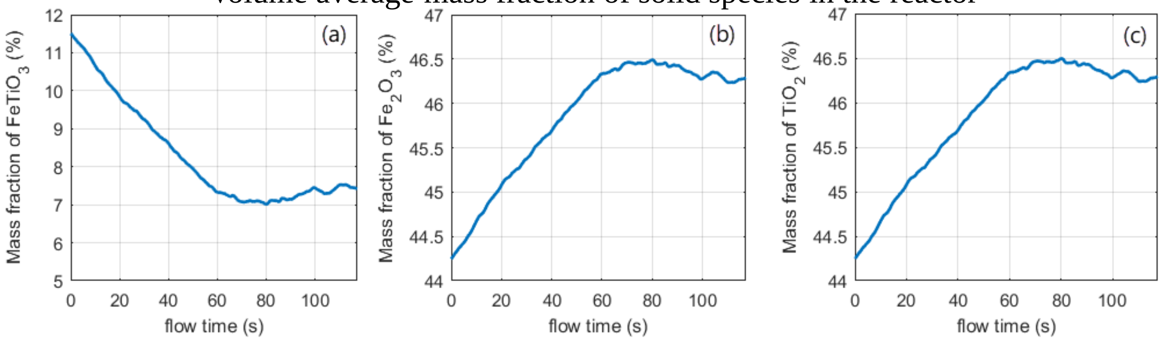


Operating Conditions

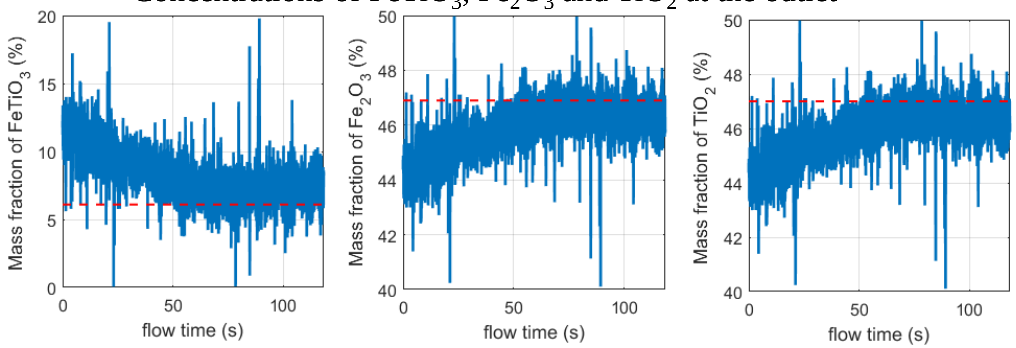
Total flow time: 120s (1sec Simulation Flow time ~ 17h)

“Pseudo-steady-state”: 90s-120s

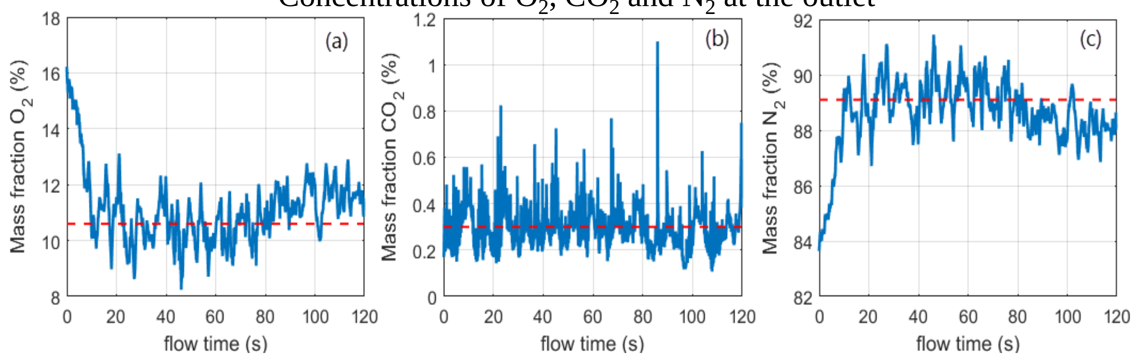
Volume average mass fraction of solid species in the reactor



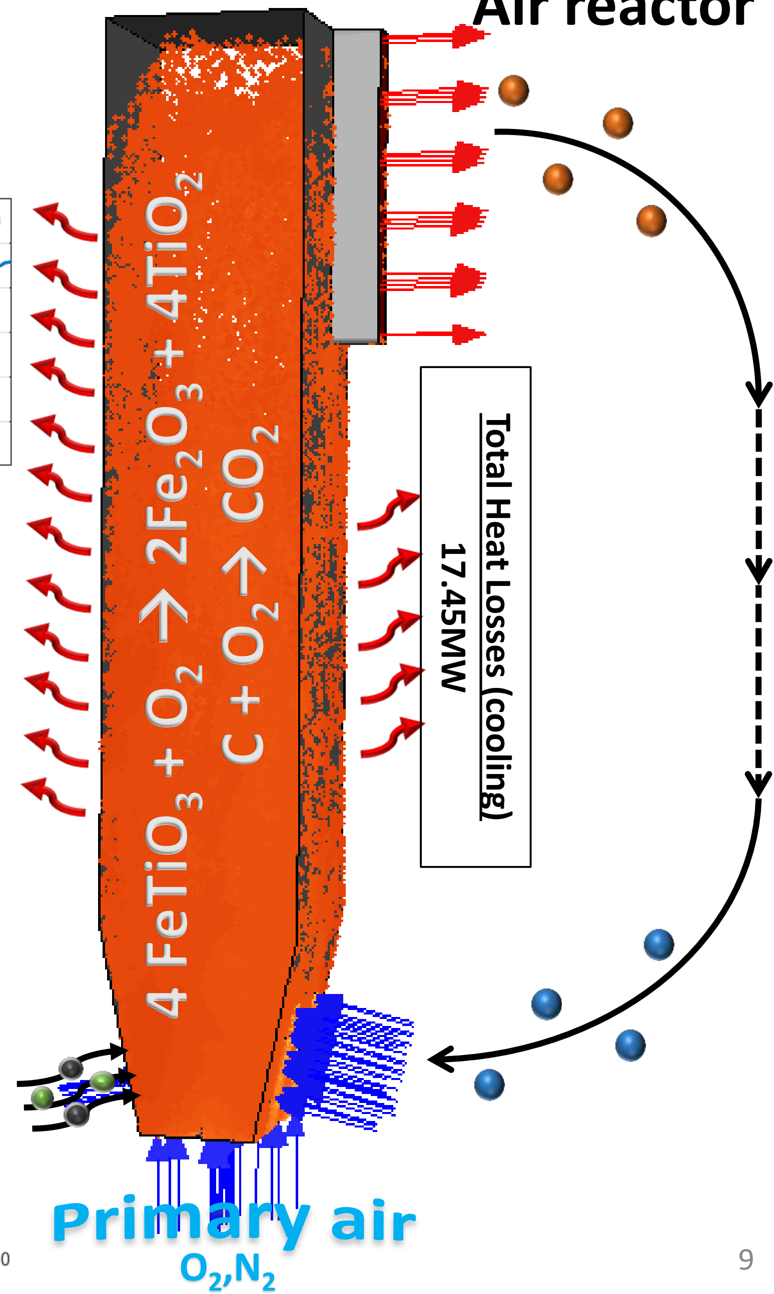
Concentrations of $FeTiO_3$, Fe_2O_3 and TiO_2 at the outlet



Concentrations of O_2, CO_2 and N_2 at the outlet



Air reactor



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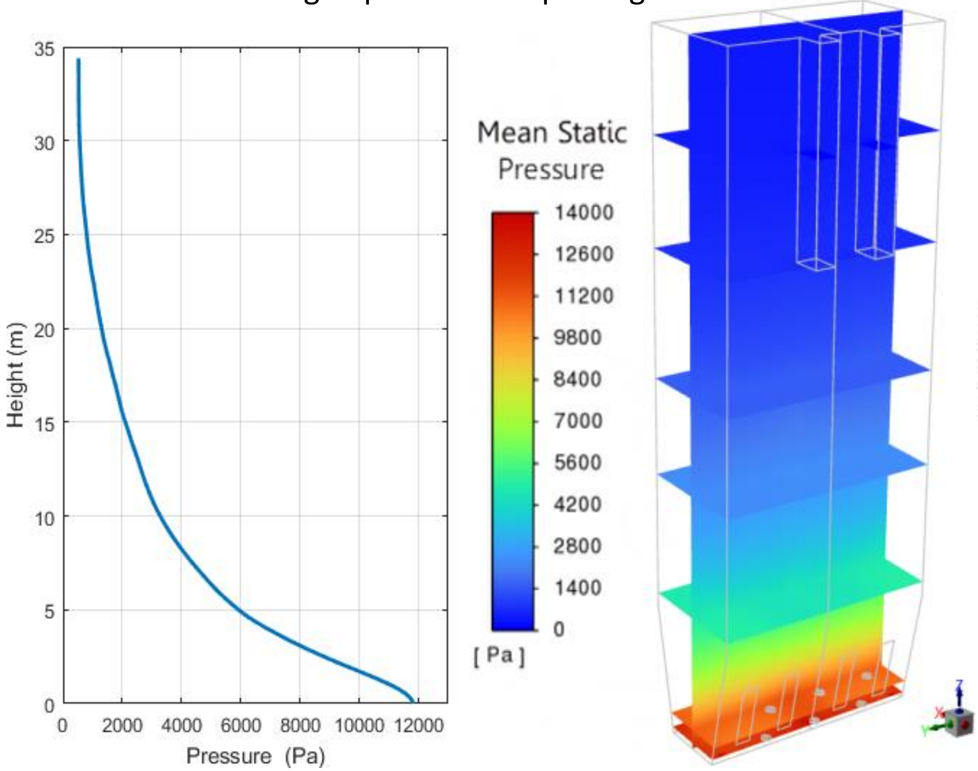
Results
Pressure Profile
& Solid Volume Fraction

Average Pressure Drop is approximately 12,600 Pa which corresponds to 37,280kg of fuel inside the reactor.

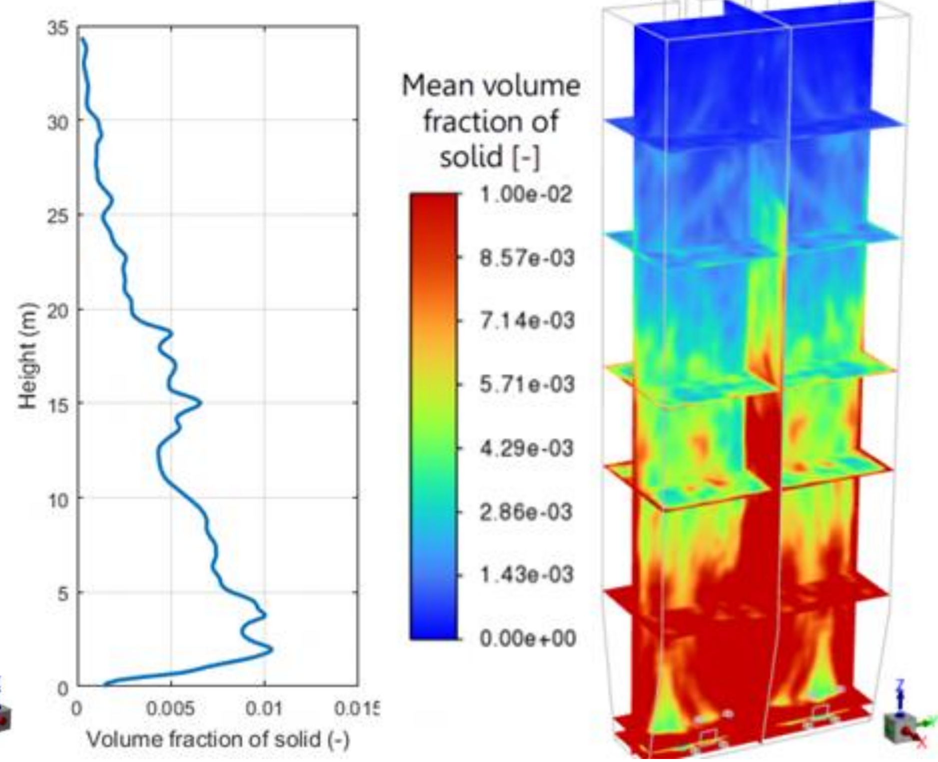
Z (m)	Pressure drop [Pa]
29.46	449.13
24.26	640.35
18.01	1606.98
13.21	2479.06
7.01	4761.69
1.01	11147.17
0.3	12686.85

The distribution of solid particles is denser in the lower regions of the reactor and becomes sparse upward, which is typical in CFB systems due to the re-circulation processes within the reactor.

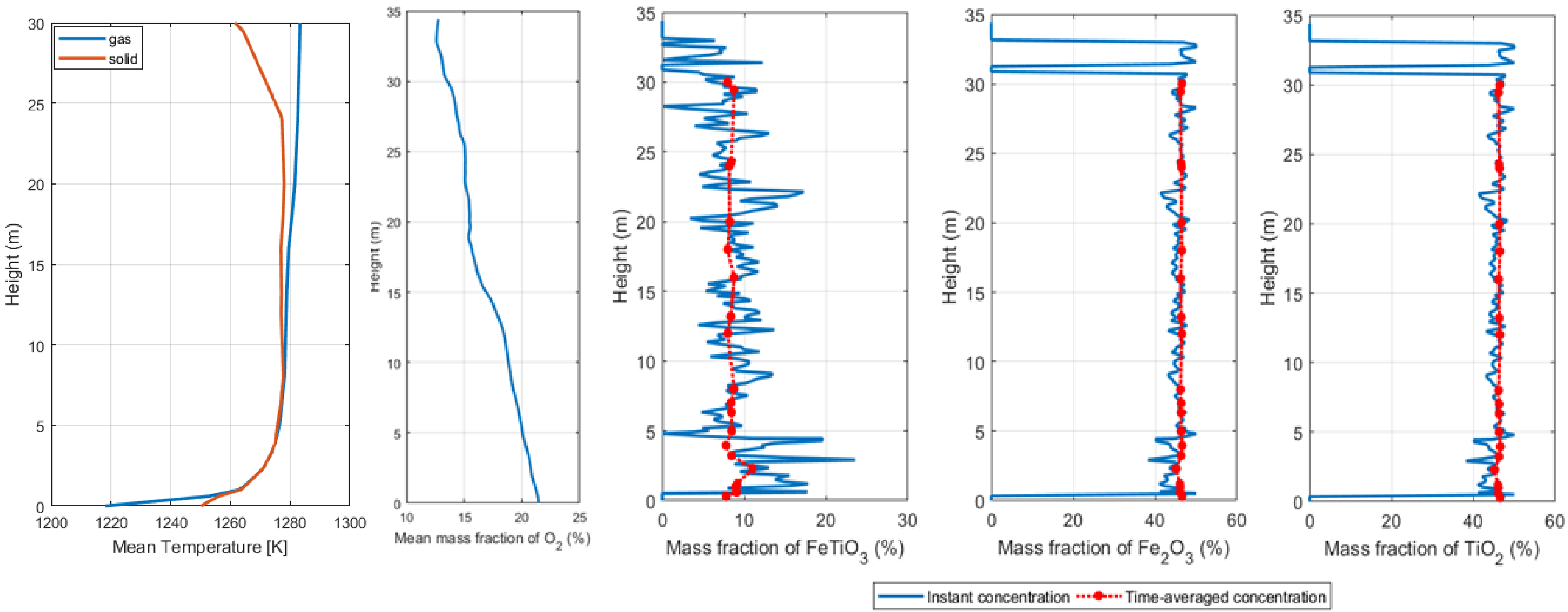
Time-averaged pressure drop along the reactor



Mean volume fraction of solid phase



Results
Mass fraction of species in the reactor



- **Gas** and **Solid** temperatures rise due to the exothermic reaction taking place at the bottom of the reactor.
- $\mathbf{O_2}$ decreases with increasing height due to the oxidation of $\mathbf{FeTiO_3}$ oxygen carrier.
- $\mathbf{FeTiO_3}$ acts as an oxygen carrier in the CLC process, the increment near the bottom occurs due to particle entry in to the reactor vessel.
- $\mathbf{Fe_2O_3}$ and $\mathbf{TiO_2}$ are the oxidized products of the reaction which are formed almost immediately as the particles enter to the reactor.

Conclusions

Co-combustion reactor

- ✓ A grid dependency study was performed using four numerical grids. The grid with **259,322** number of elements, provides an acceptable average percentage error equal to **14.74%**.
- ✓ A comparison was made between Gidaspow, fluent EMMS model and Artificial Neural Network EMMS drag model by Certh. The **ANN EMMS** predicts the pressure profile very accurately according to the provided experimental data.
- ✓ The CFD simulation of the full-scale Co-Combustion reactor predicts:
  - An average percentage error of the pressure drop equal to **10.85%**
  - An average percentage error of the mole fraction of O_2 at the outlet **13.2%**

Air reactor

The predictions of the model regarding the air reactor boiler showed very good agreement with the results of the ASPEN simulation process.

- ✓ An average percentage error of the gas temperature at the outlet equal to **0.8%**
- ✓ An average percentage error of the gas mass flow rate at the outlet equal to **1.8%**
- ✓ An average percentage error of the gas species concentrations at the outlet less than **10%**
- ✓ An average percentage error of the solid species concentrations at the outlet less than **5%**

Thank you for your attention!!!