FLEX FLORES: RFCS project

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Research Fund
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CERTH – CFD MODELING (BFB HEAT EXCHANGER) - OVERVIEW

- Examination of a bubbling fluidized bed (BFB) as a Heat exchanger (HE) concept based on the operating/design data of INTREX superheater concept

- The HE can be used as a heat storage tank taking advantage its relatively large high temperature (bubbling) fluidized bed inventory

- 3D transient simulation of the flow patterns and heat extraction from the HE heat pipes by means of ANSYS Fluent v17.1

- Use of the pure Eulerian-Eulerian two fluid model (TFM)

- Solution of the heat transfer to the steel pipes through User Defined Functions (UDFs) – The temperature profile across the steel tubes is calculated

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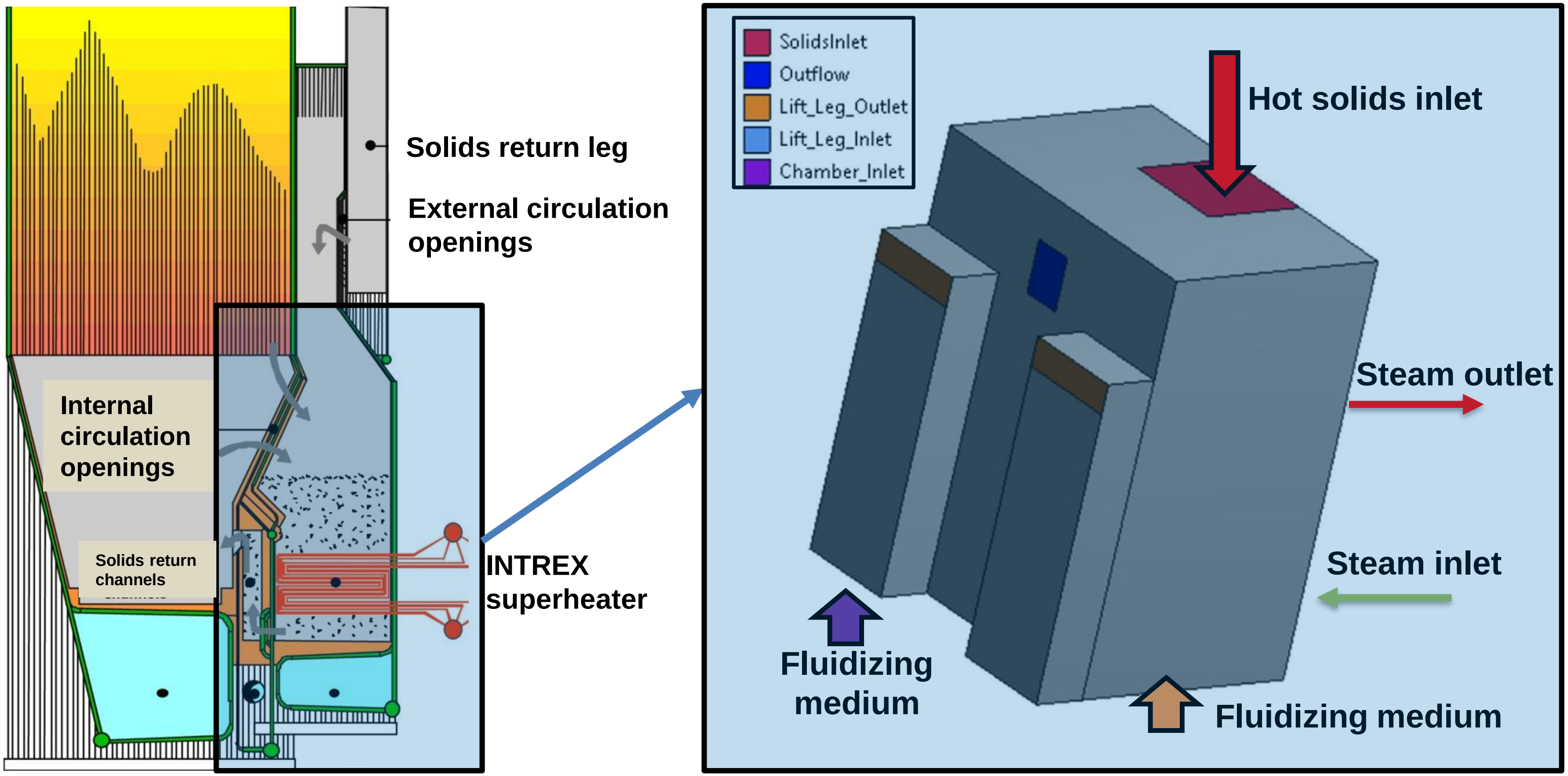
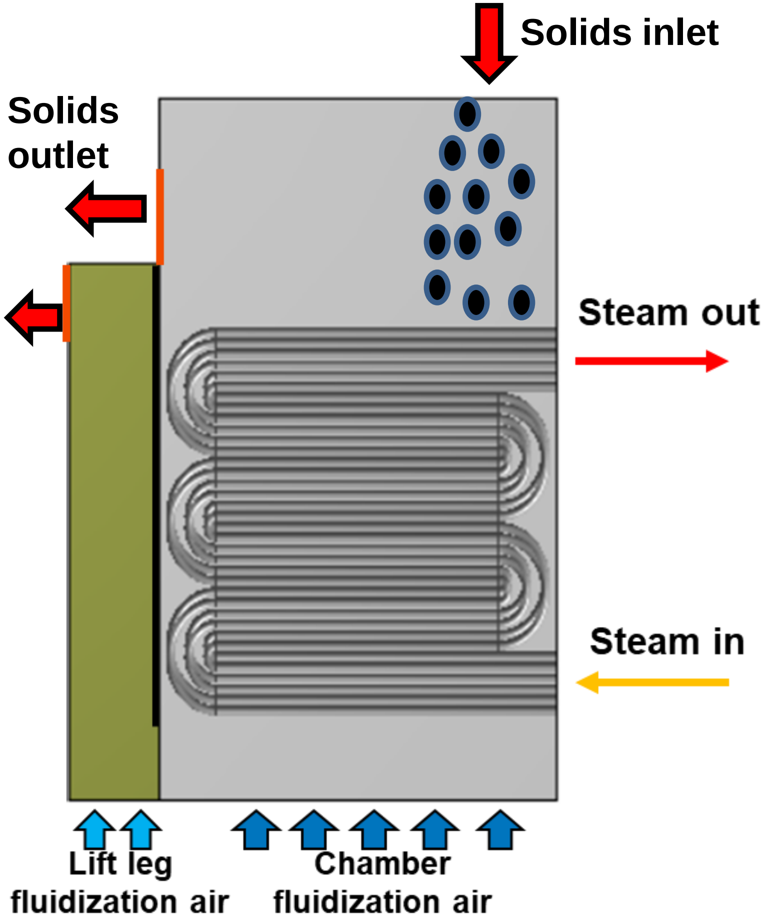
CERTH – CFD MODELING (BFB HEAT EXCHANGER) - OVERVIEW



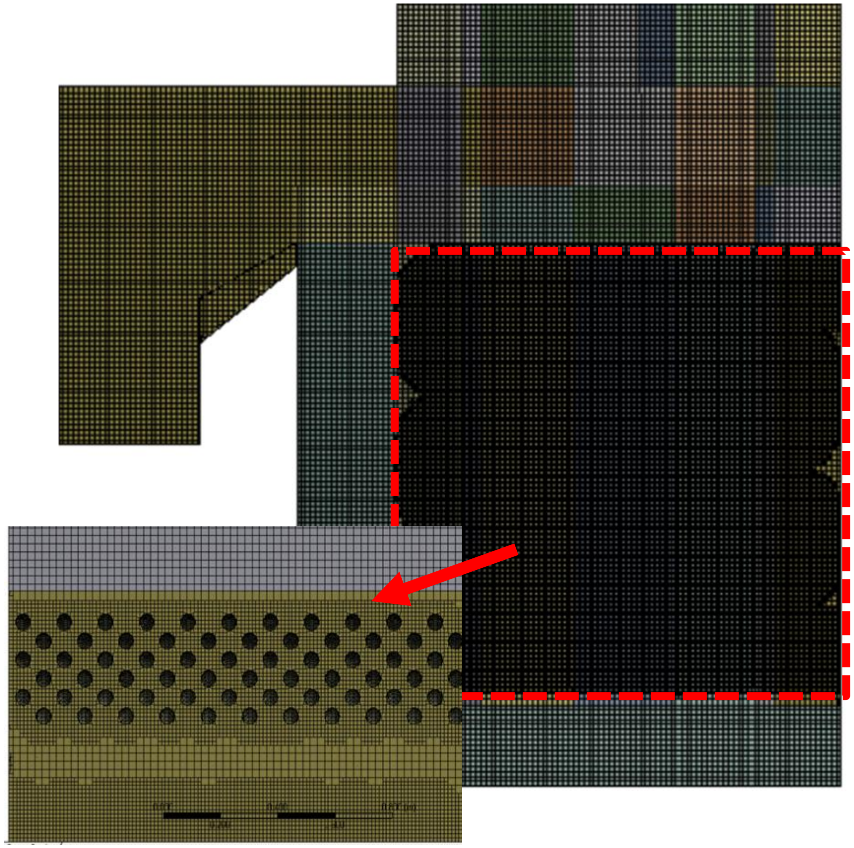
Source: *Modern CFB Concept for Combustion of Recovered Fuels: Design for Improved Availability*

CERTH – CFD MODELING (BFB HEAT EXCHANGER) – DESIGN & MESH

BFB HE Design



BFB HE Mesh



- Due to geometry complexity use of CutCell method with 7.4 million elements
- Simulation of a symmetry problem with 3.4 elements to speed-up computation

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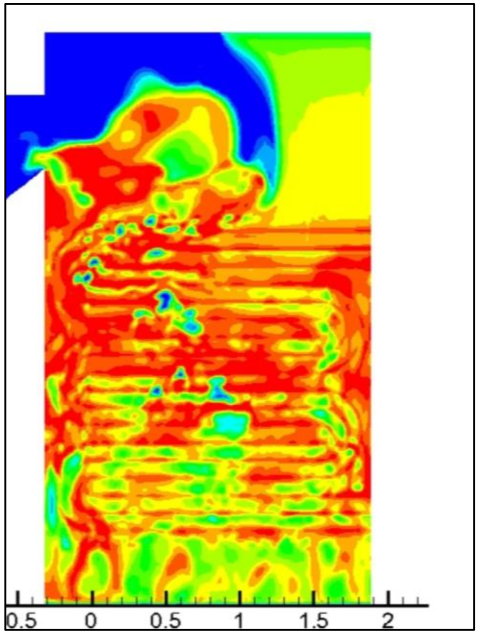
CERTH – CFD MODELING (BFB HEAT EXCHANGER) - METHODOLOGY

Heat transfer algorithm: In each iteration:

1. The total Q [W] in each tube bundle is retrieved from the solver
2. Input: steam properties (c_p), mass flow rate and T_{in},
3. Output: T_{out}
4. The temperature along the tubes in calculated based on a linear interpolation between T_{in} and T_{out}. Solution proceeds until quasi-equilibrium.



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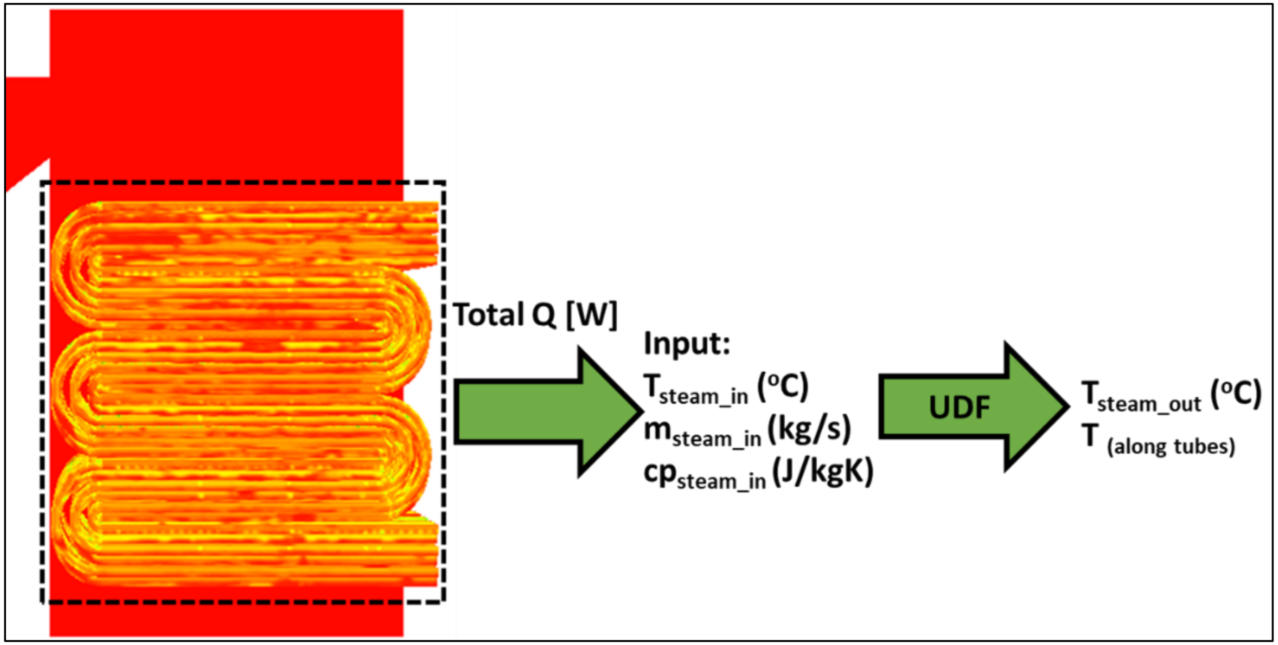
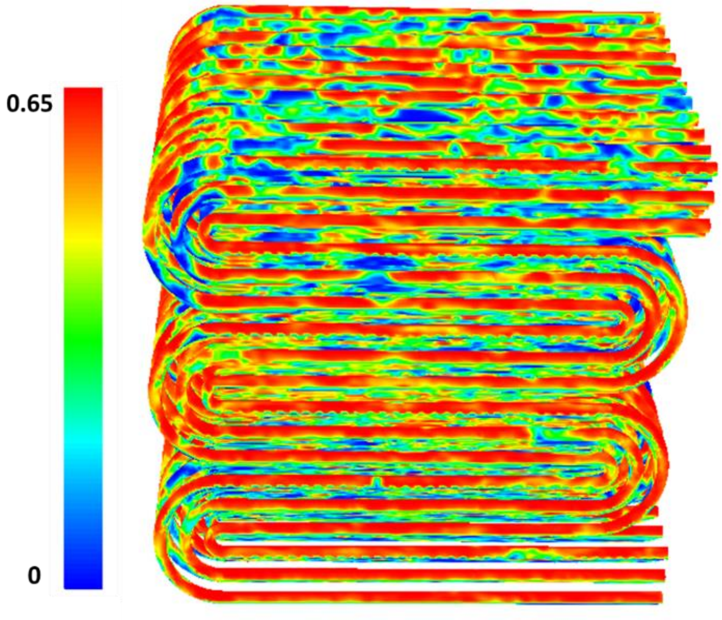


Flow hydrodynamics

Heat transfer model algorithm, applied by CERTH

CERTH – CFD MODELING (BFB HEAT EXCHANGER) - RESULTS



Instantaneous solids volume fraction at t=10 sec

Flow hydrodynamics:
The height of the bubbling bed is higher than that o the last passes of the tubes bundles. Near the last pass the fluid flow is more dilute than near the bottom, a fact that might affect the HTC values

Total heat transfer rate:
(a) Based on heat transfer algorithm: ~1.35 MW for the volume simulated (½). (Value close to the expected)
(b) Based on a simplified approach (a mean steam temperature is imposed at tubes walls): ~1.15 MW

Difference between the two approaches: 15 %

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CERTH – CFD MODELING (BFB HEAT EXCHANGER) – CONCLUSIONS

- A 3D CFD model of the integrated heat exchanger of an industrial CFB boiler has been developed based on design and operating data of INTREX heat exchanger.
- The model was utilized to perform transient simulations of the heat transfer process from the bubbling bed to the tube buddles.
- Simulation of the HE is demanding, due to its complex geometry and simulation of a symmetry problem by using CutCell method is necessary to speed-up calculations.
- An analytical model has been applied that explicitly takes into account the tube bundles arrangement.
- Based on the results the flow hydrodynamics and total heat transfer rate are represented with an acceptable accuracy

Main outcome: This analysis proves the importance of: 1) explicitly modelling the heat transfer surfaces and 2) using an analytical model that calculates the temperature of the working fluid inside the tube bundles.

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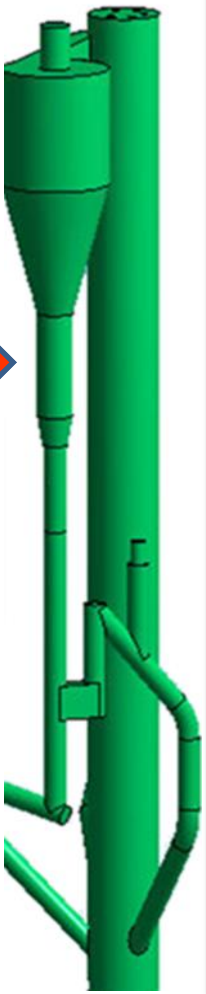
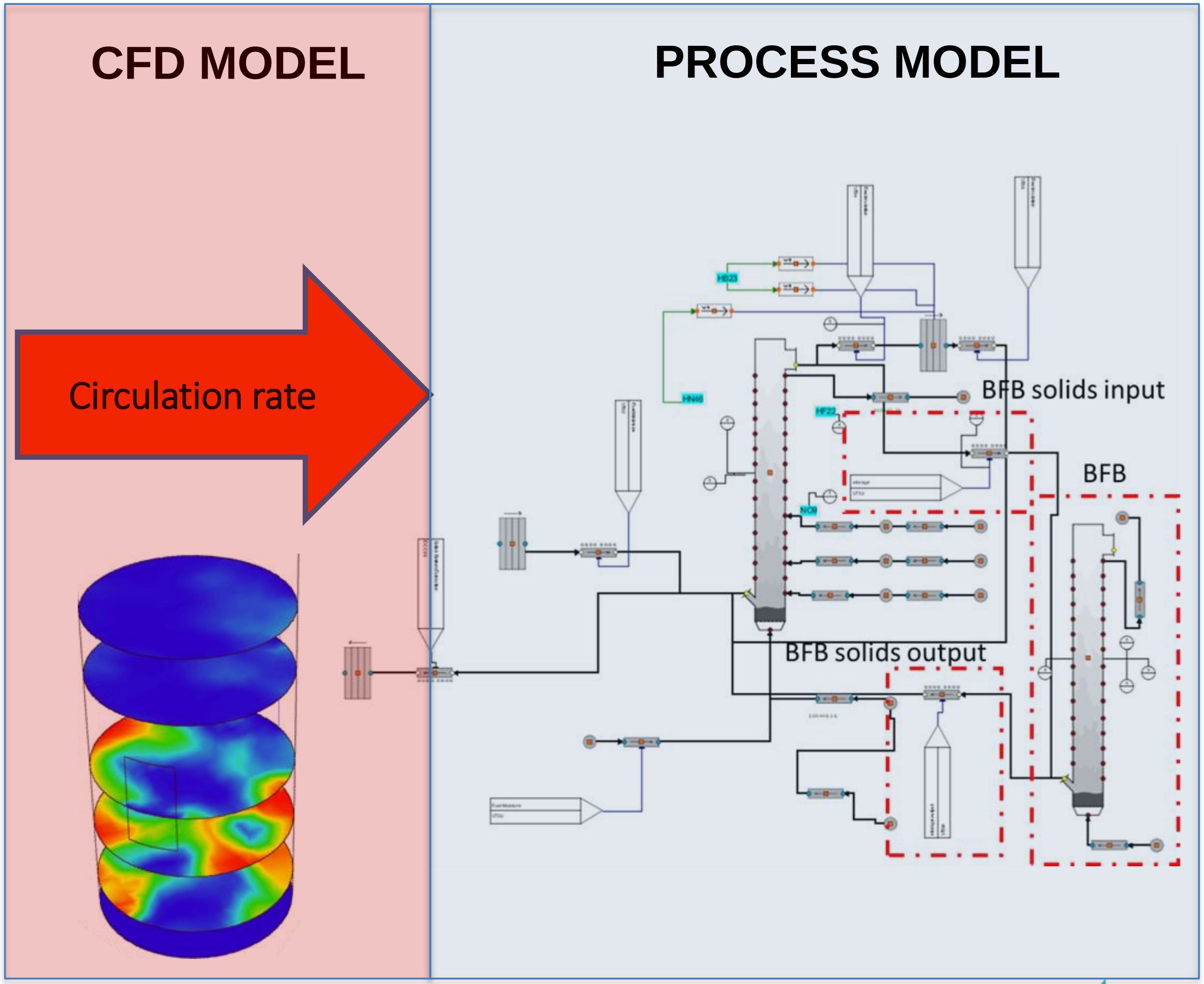
CERTH – 1MW UNIT SIMULATION - OVERVIEW

Input: Thermal Load, gas-solid properties



Simulation of CFB600 unit for 100 % German lignite at three different loads:
100 %, 80 %, 60 %



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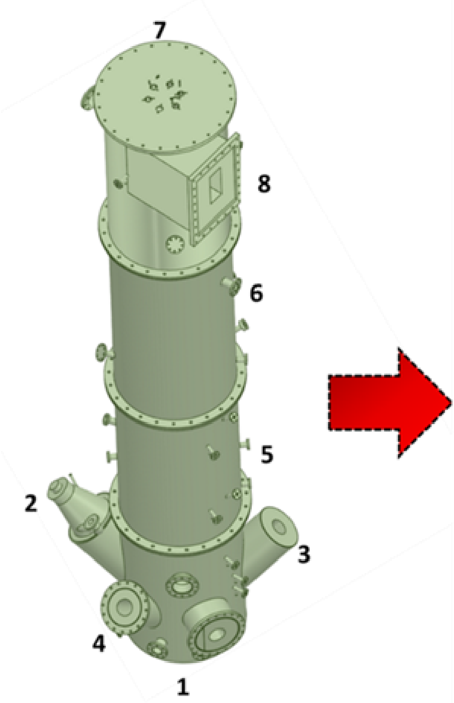
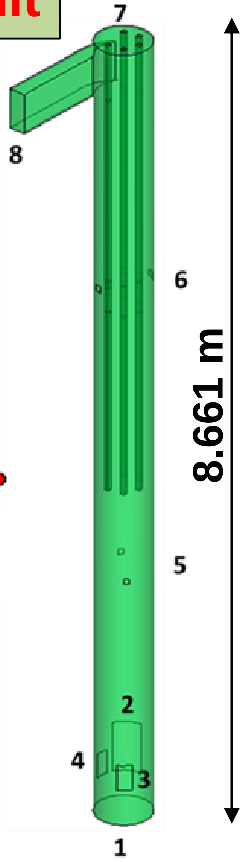
CERTH – CFD MODELING (1MW UNIT) - METHODOLOGY

TUDA 1 MW_{th} unit



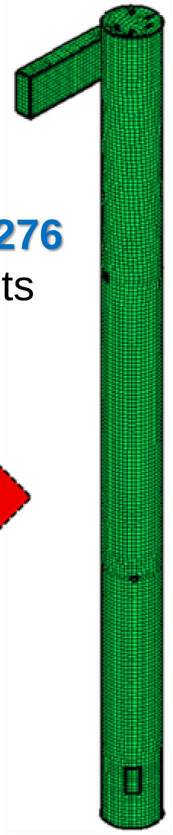
Initial Geometry



Geometry clean-up

<u>Coarse grid</u> with **30,276 hexahedral** elements ($D_{cell}/D_p \approx 460$)

1: **Distributor**, D=0.59 m
2: **Auxiliary Burner**
3: **Loop Seal 1**
4: **Loop Seal 2**
5: **Secondary air**
6: **Secondary air**
7: **Water Lances**
8: **Outlet**



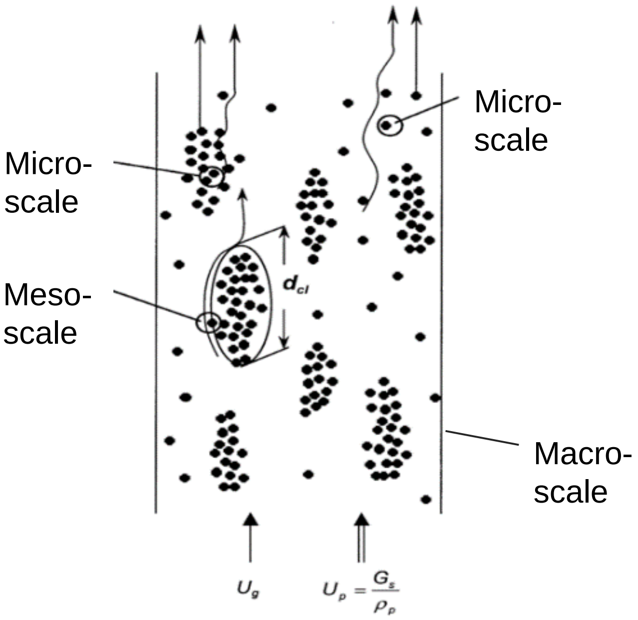
Domain discretization

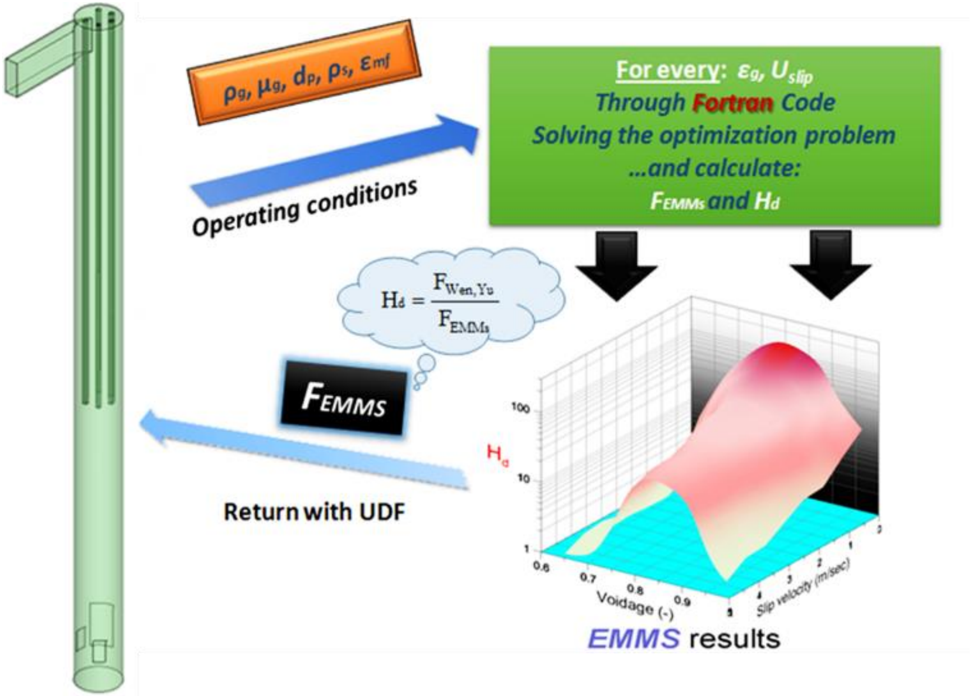
Initially: **<u>Validation of CFD models for the lignite firing case at 60 %, 80 % and 100 % load</u>**

CERTH:
EMMS /Gidaspow drag force model comparison
3D CFD simulation*
Isothermal conditions

***Platform: ANSYS Fluent v17.1**

CERTH – CFD MODELING (1MW UNIT) – DRAG FORCE MODEL





- Use of the innovative EMMS model that has been developed by CERTH and validated for experimental data from different units
- A map has been constructed for the operating conditions and specific fuels used in the 1 MW$_{th}$ unit
- The homogeneous Gidaspow model is also applied and compared with EMMS model

CERTH – CFD MODELING (1MW UNIT) – SETUP

Test Case	Grid	Drag Force Model	Load %	Inventory [kg]
Case A	Coarse	EMMS	60	117
Case B	Coarse	Gidaspow	60	117
Case C	Coarse	EMMS	80	122.6
Case D	Coarse	Gidaspow	80	122.6
Case E	Coarse	EMMS	100	136.5
Case F	Coarse	Gidaspow	100	136.5

Simulated cases matrix

Parameter	Value	Parameter	Value
d_p, μm	240	ρ_s, kg/m^3	2650
ρ_g, kg/m^3	0.34	μ_g, kg m^{-1}s^{-1}	$3.91085 * 10^{-5}$

Gas-solid properties

$$\overline{d_p} = \frac{1}{\sum^{all\ i}(x/d_p)_i} \quad (1)$$

- The inert material is simulated only (the fuel flow is neglected in this set of cases)
- A monosized approach is used for the solids diameter, eq (1)
- The gas properties are obtained by APROS modelling tool, considering full fuel combustion

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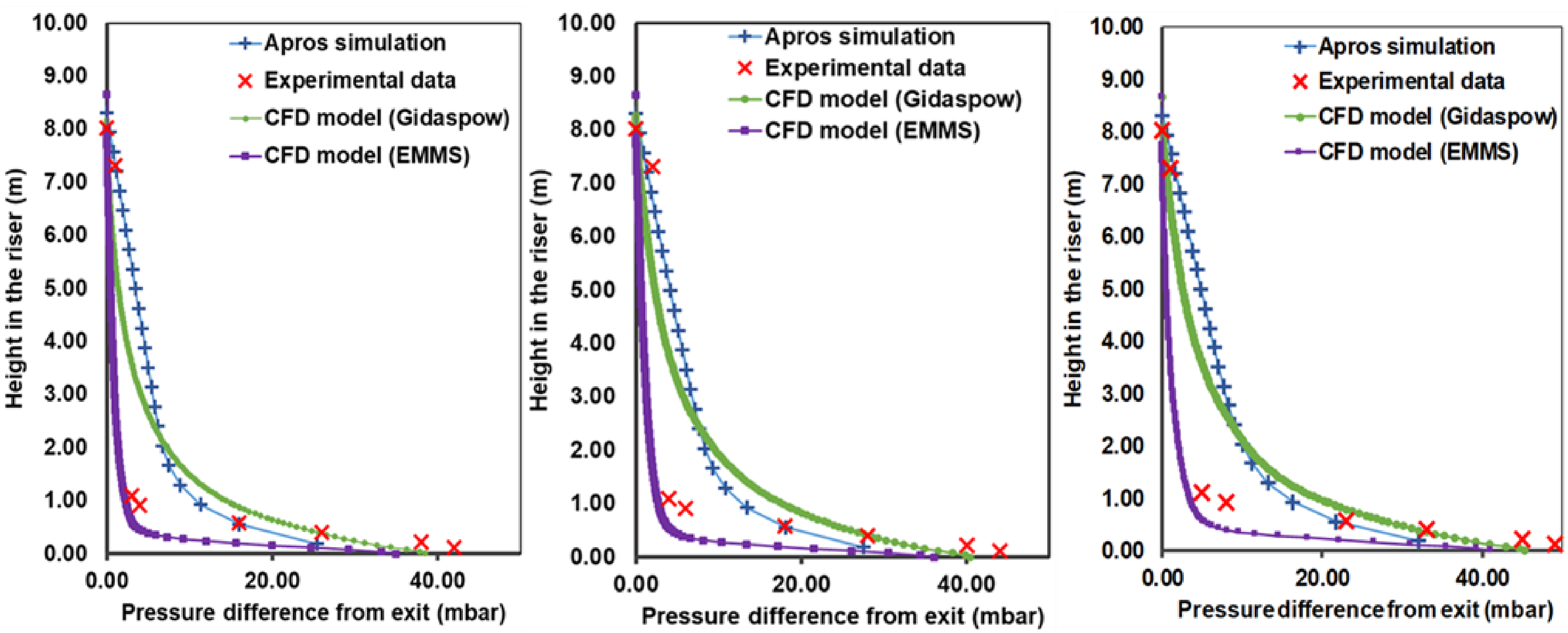
CERTH – CFD MODELING (1MW UNIT) – RESULTS



60% load

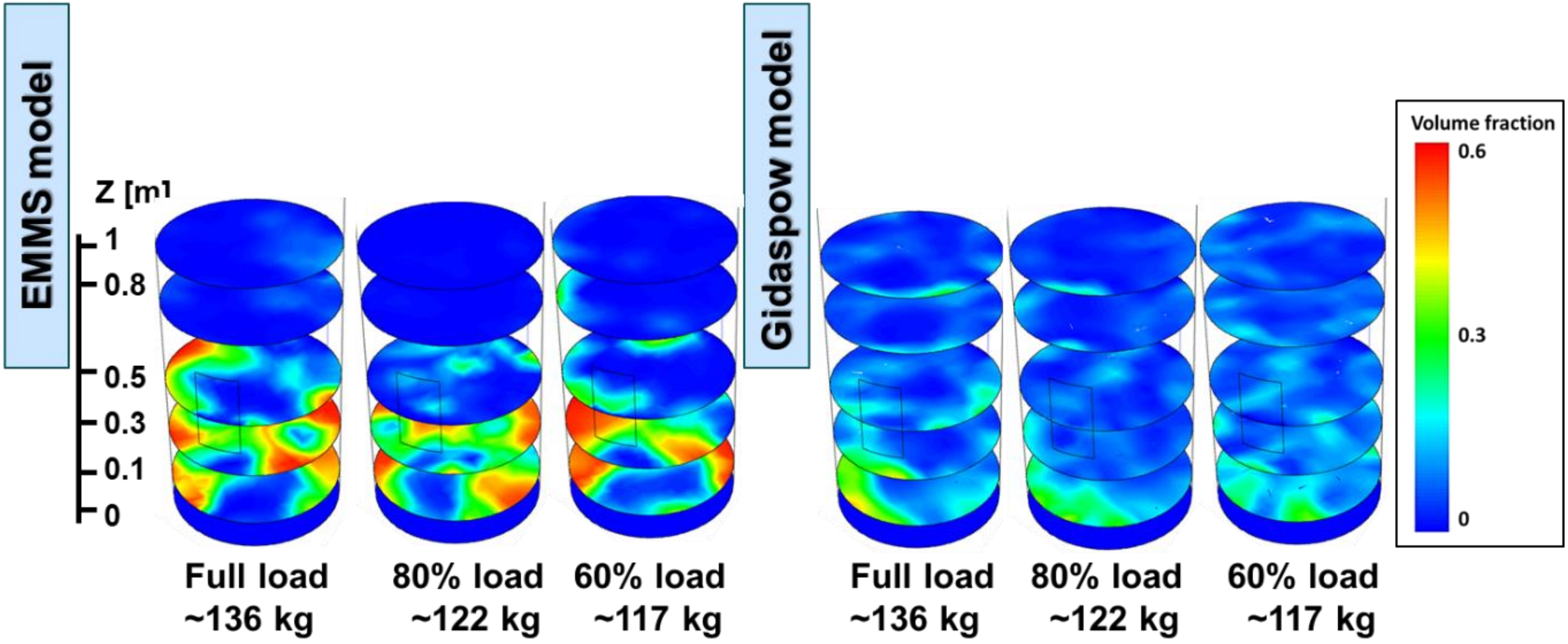
80% load

100% load

Predicted pressure profiles (axial)

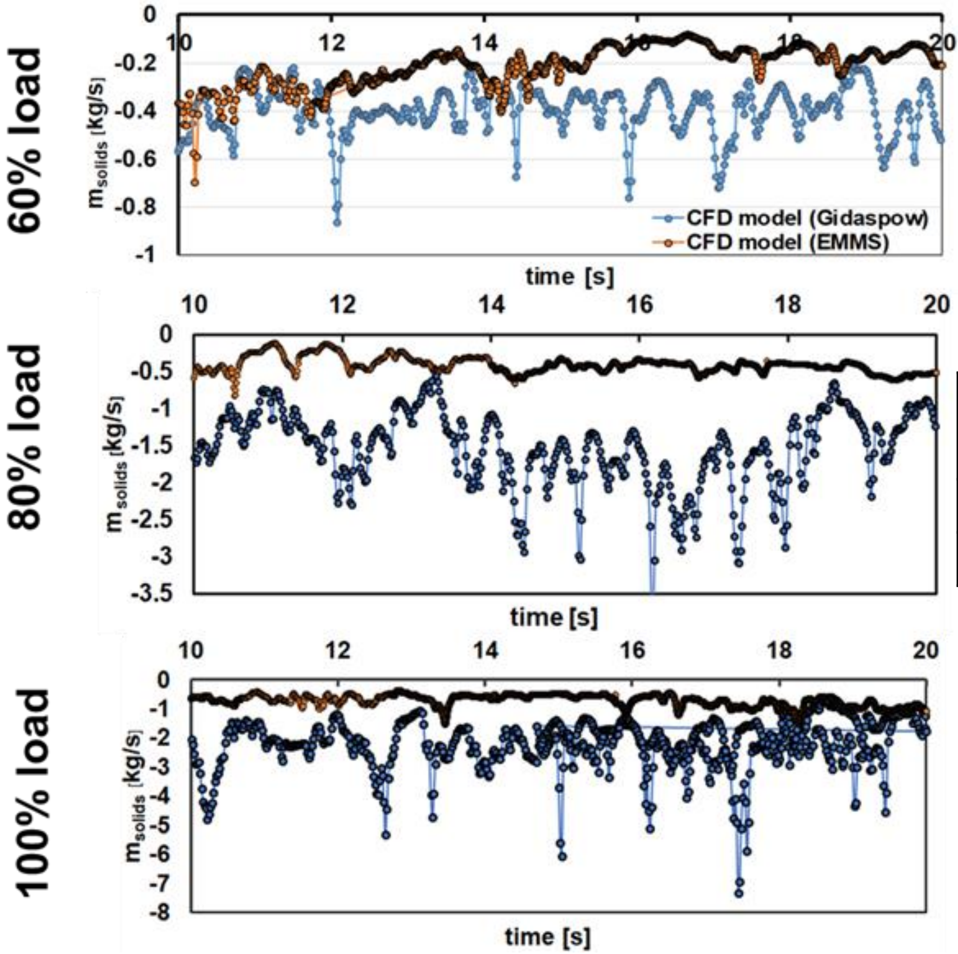
Better pressure profile prediction with the EMMS model with respect to Gidaspow model

CERTH – CFD MODELING (1MW UNIT) – RESULTS



Solids volume fraction at t=15 sec near the bottom zone

CERTH – CFD MODELING (1MW UNIT) – RESULTS



Model	Thermal load		
	60%	80%	100%
Gidaspow	~0.4 kg/s	~1.53 kg/ s	~2.4 kg/s
EMMS	~0.21 kg/s	~0.42 kg/ s	~0.77 g/s

Time dependent solids mass flux (riser exit)

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CERTH – PROCESS MODELING - OVERVIEW

- Development in APROS of a 1D dynamic model of the TUDA CFB pilot plant
- Validation against experimental data from TUDA and data from CFD simulations
- Examination of a bubbling fluidized bed (BFB) as a thermal energy storage concept (TES) to increase ramp up/down rates.
- Investigation of fuel staging as a concept to improve the technical minimum load operation of the plant

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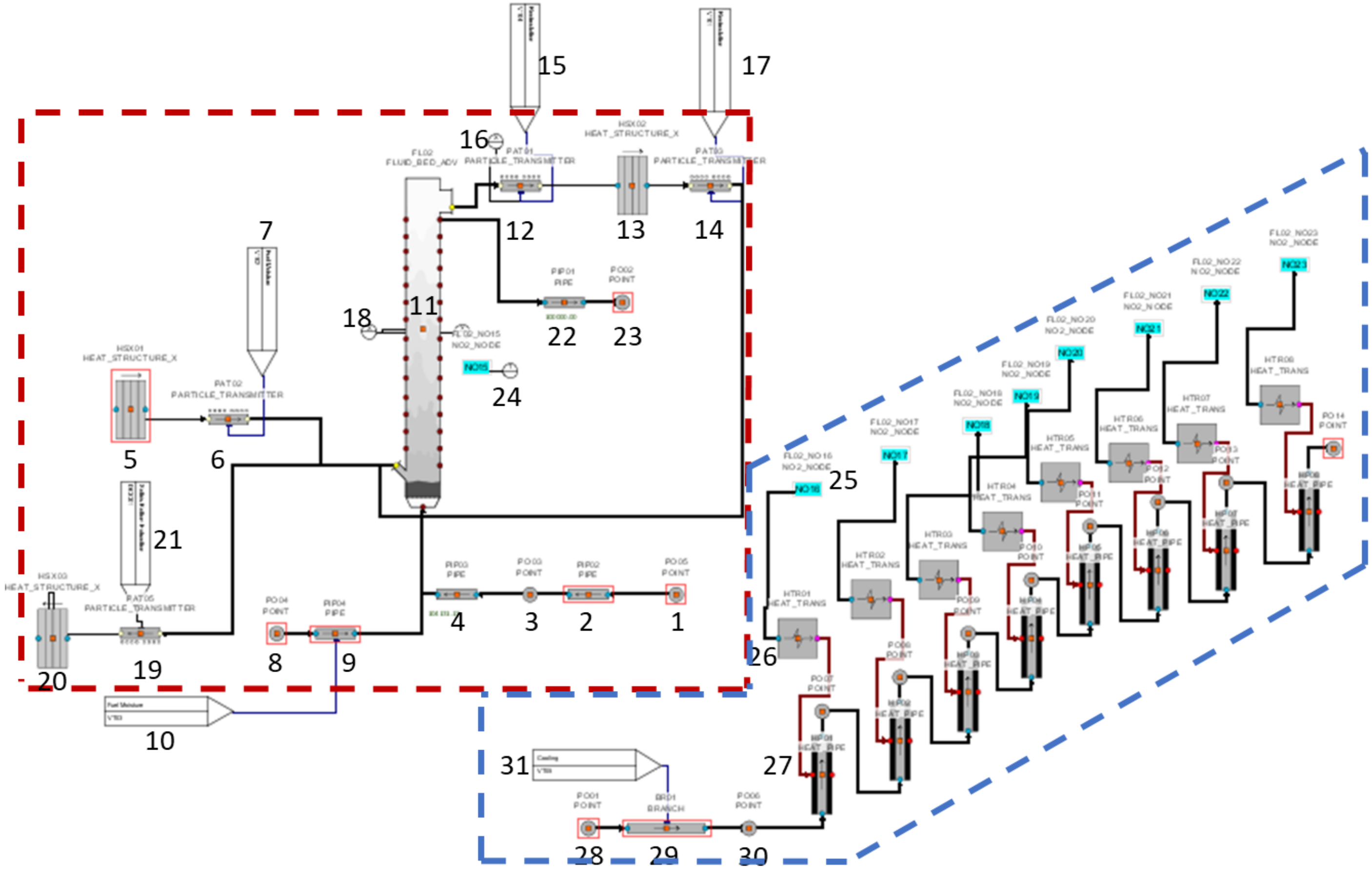
CERTH – PROCESS MODELING – APROS MODEL



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CERTH – PROCESS MODELING – EXAMINED CONDITIONS

Main Inlet and operational data for the different loads tested

Property	**60%**	**80%**	**100%**
Primary air (kg/s)	0.1795	0.1831	0.1830
Secondary air (kg/s)	0.0000	0.0510	0.1184
Burner air (kg/s)	0.0252	0.0359	0.0359
Loop seals air (kg/s)	0.0088	0.0103	0.0113
Fuel mass rate (kg/s)	0.04716	0.06406	0.07831
Inventory (kg)	117.0	122.6	136.5
Heat loss from walls (kW)	170	270	350

Dynamic simulation: 80%->60%->80%

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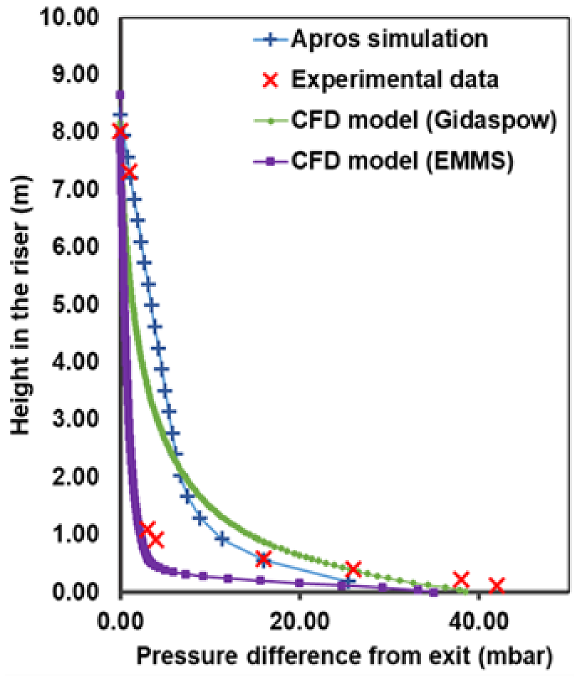
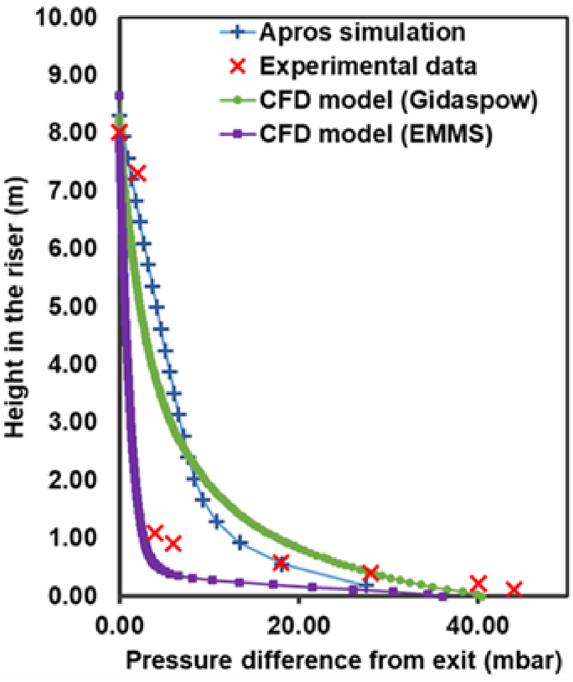
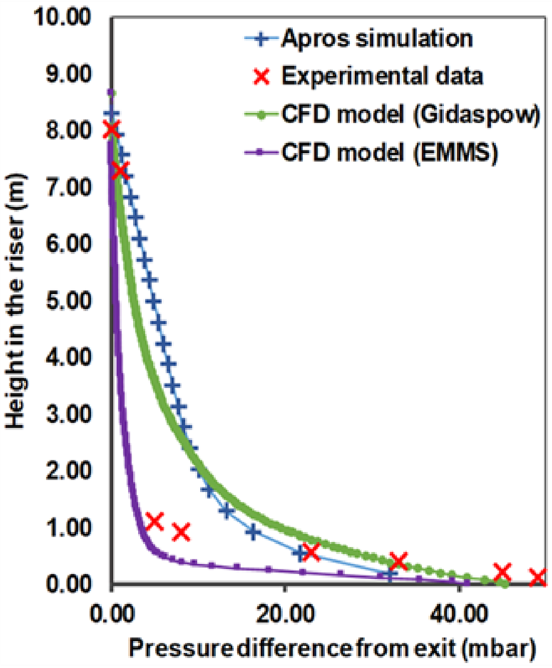
CERTH – PROCESS MODELING – RESULTS ST. ST.



60% load



80% load



100% load

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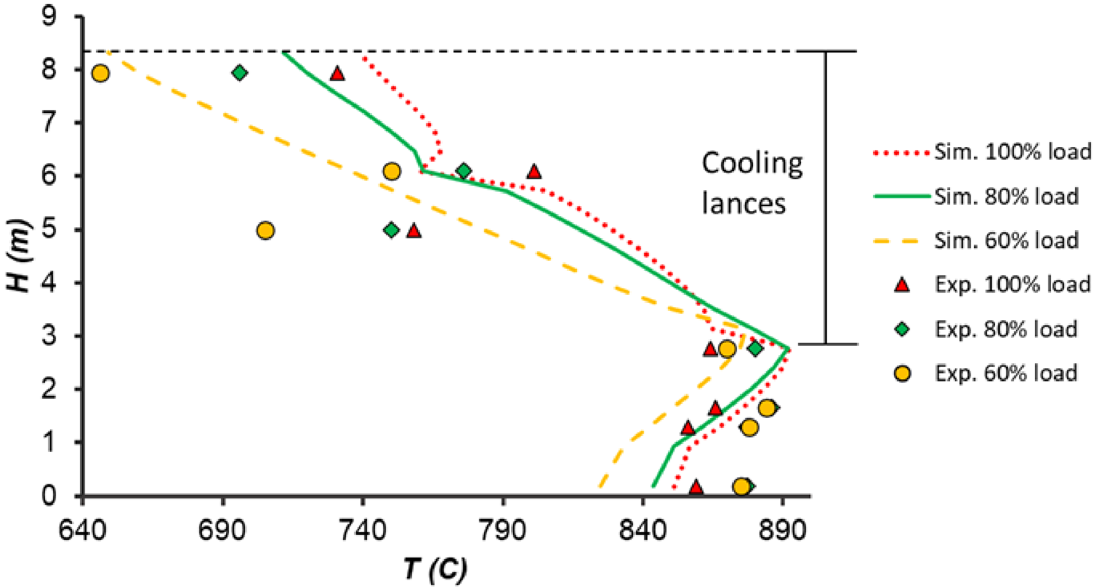
CERTH – PROCESS MODELING – RESULTS ST. ST.



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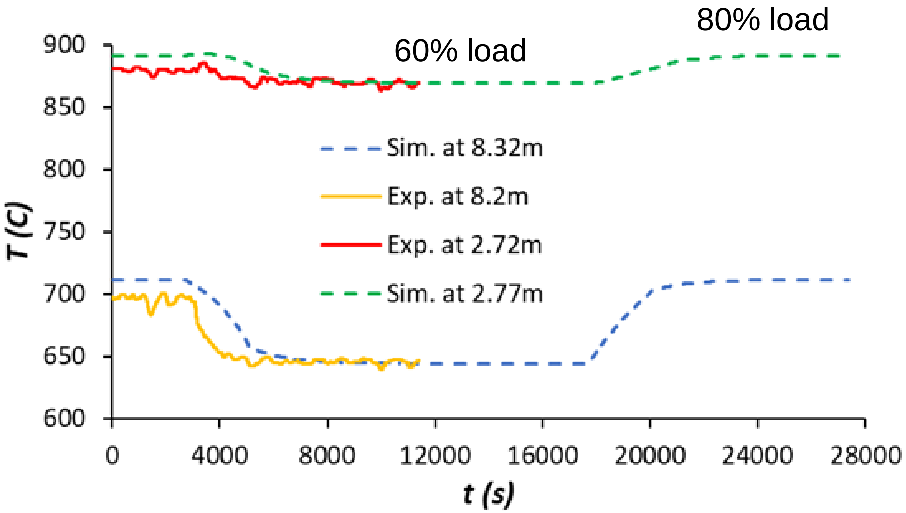
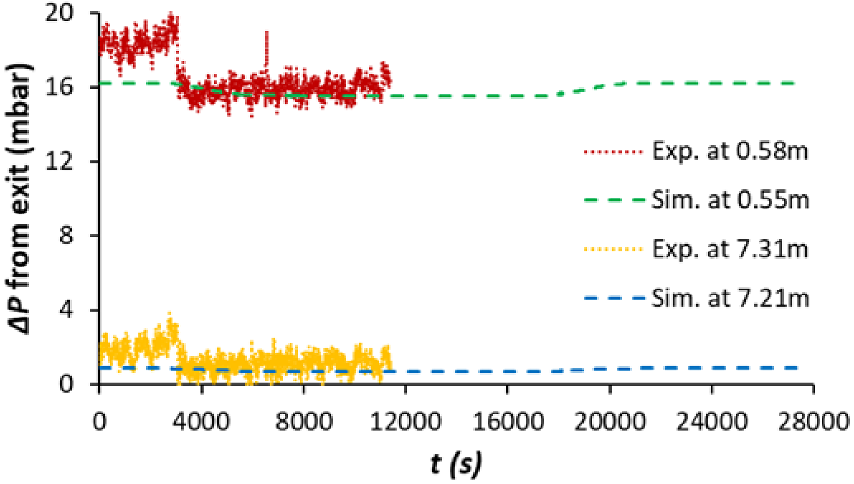
CERTH – PROCESS MODELING – RESULTS DYNAMIC





Fairly good agreement between the results of the simulation and those of the experiments

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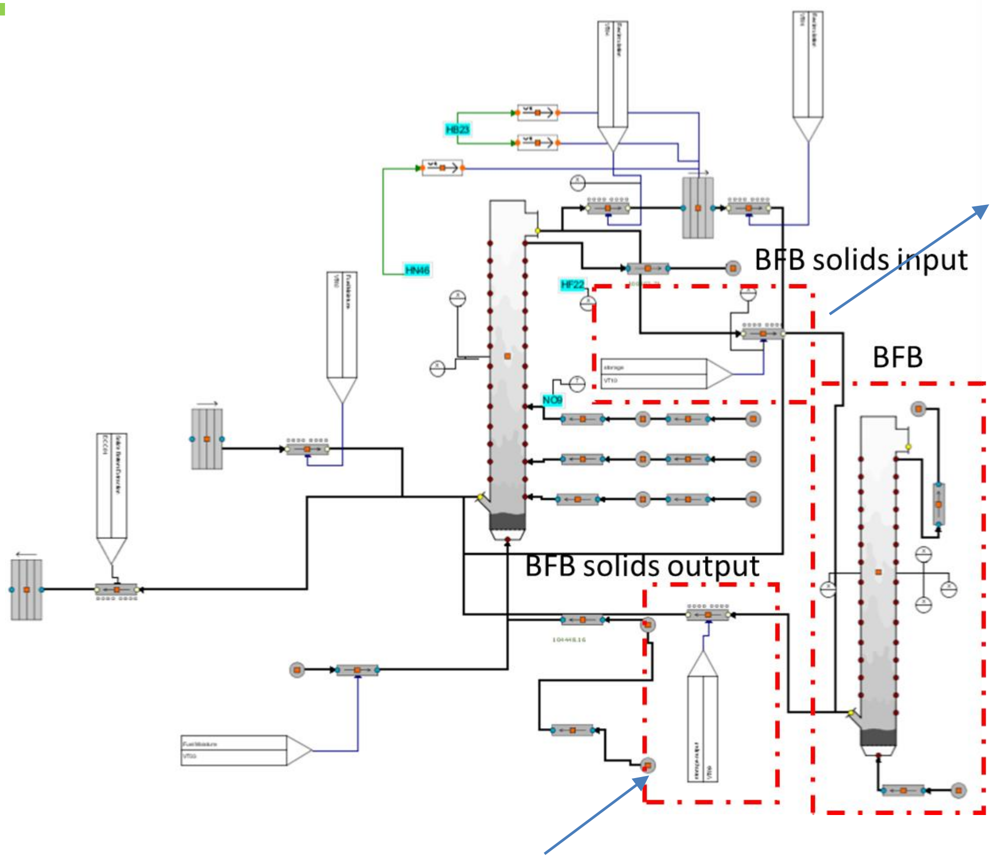
CERTH – PROCESS MODELING – BFB MODEL



During ramp down: a particle transmitter removes 5% from the mass flow of the recirculation and transmits it to the bottom of the BFB, until the desired inventory is reached.

During ramp up: a particle transmitter removes particles from the bottom of the BFB and transmits it to the bottom of the CFB, until the desired inventory is reached. Rate is such that to achieve the same transition time as the ramp down.

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CERTH – PROCESS MODELING – EXAMINED CASES TES

	Case 1 (with TES)			Case 2 (without TES)		
Property	**100%**	**80%**	**60%**	**100%**	**80%**	**60%**
Primary air (kg/s)	0.183	0.1831	0.1795	0.183	0.1831	0.1795
Secondary air (kg/s)	0.1184	0.051	0	0.1184	0.051	0
Burner + loop seal air (kg/s)	0.0849	0.0765	0.0572	0.0849	0.0765	0.0572
Fuel rate (kg/s)	0.0751	0.06143	0.0452	0.0751	0.06143	0.0452
CFB inventory (kg)	190	180	170	190	190	190
BFB inventory (kg)	3	13	23	-	-	-

Simulation scenario: 100%-80%-60%-80%-100%

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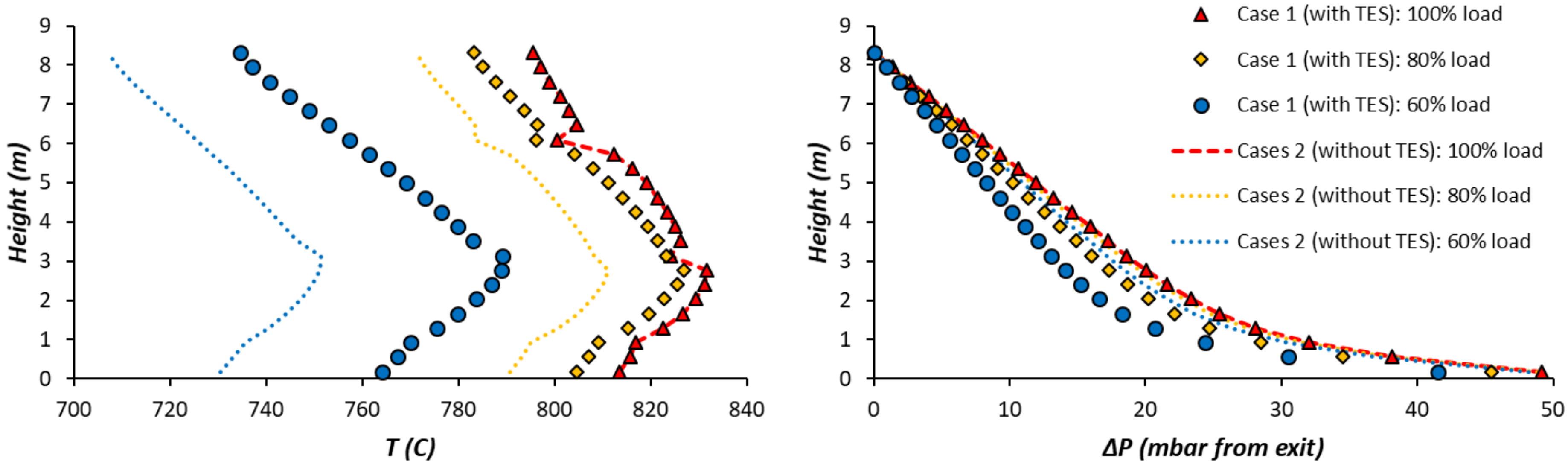
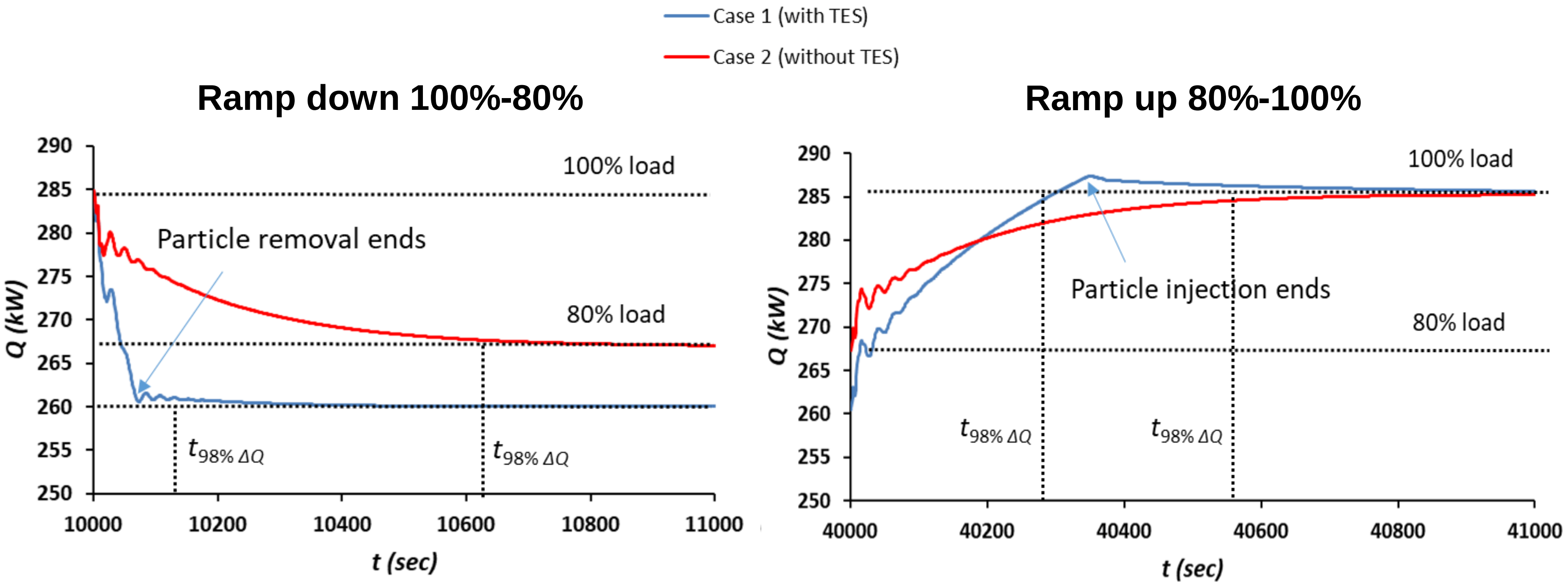
CERTH – PROCESS MODELING – RESULTS TES



- Case 1: lower temperature drops compared to case 2.
- Case 2: pressure drop remains relatively constant between the loads.

CERTH – PROCESS MODELING – RESULTS TES



Ramp down 100%-80%

Ramp up 80%-100%

$t_{\text{no inv change}}/t_{\text{inv change}} \approx 4.8$ (or 3.79)

$t_{\text{no inv change}}/t_{\text{inv change}} \approx 1.99$ (or 1.1)

*t is defined as the time required to reach 98% of the total ΔQ
(or 63%, which is the analogue filter constant)

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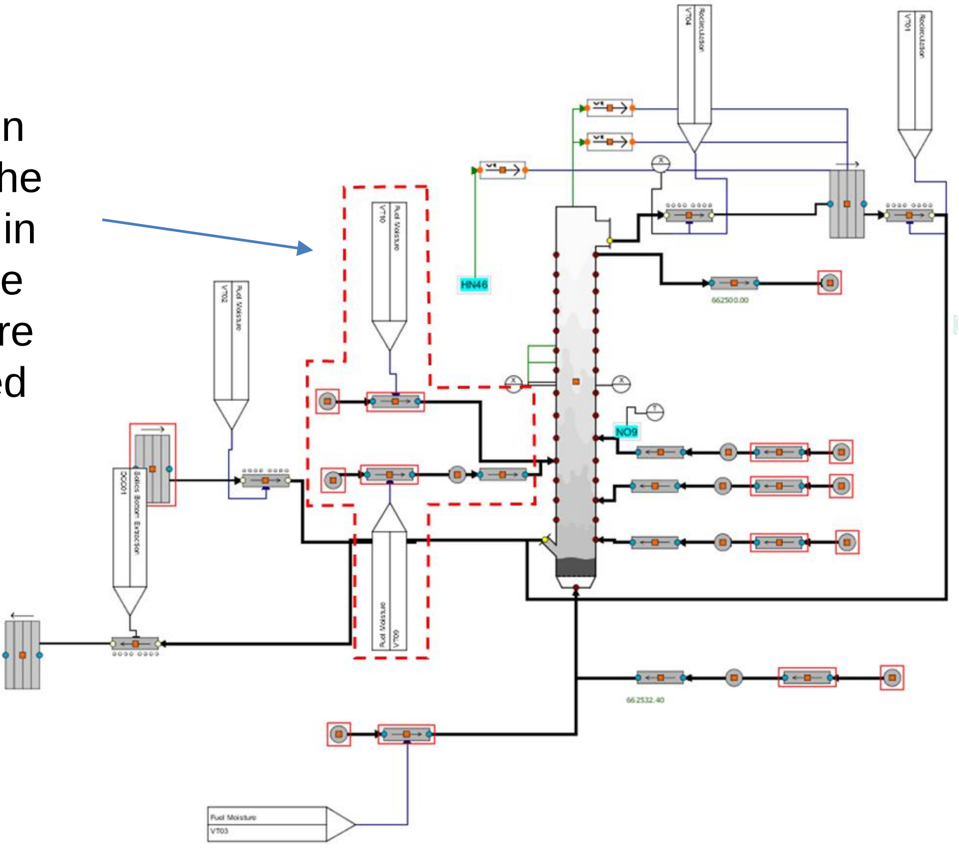
CERTH – PROCESS MODELING – FUEL STAGING MODEL

Due to restrictions in the Apros software the fuel staging is done in gaseous form: same heat and temperature profiles are achieved with the reference case



CERTH – PROCESS MODELING – FUEL STAGING CONDITIONS

Corresponds to the 60% load operation of the TUDA pilot plant

Property	**Value**
Primary air (kg/s)	0.1795
Secondary air (kg/s)	0.0000
Burner air (kg/s)	0.0252
Loop seals air (kg/s)	0.0319
Total fuel mass rate (kg/s)	0.0452
Flue gas mass rate (kg/s)	0.2892
Inventory (kg)	123
Temperature of primary air (C)	69
Temperature of fuel (C)	20
Moisture	45%

- Examined staging heights: 3m, 4m and 5m
- Examined primary (inlet from CFB bottom) to secondary (staging) fuel ratios: 80%/20%, 60%/40%, 40%/60%, 30%/70%

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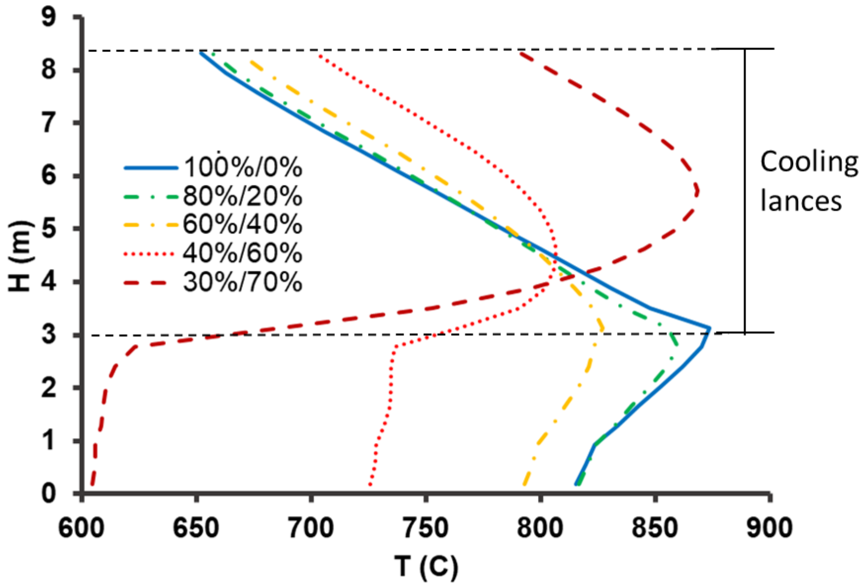
CERTH – PROCESS MODELING – FUEL STAGING RESULTS

Staging at 3 m (coincides with the position of the cooling lances)



- Both the 40%/60% and 30%/70% primary/secondary fuel ratios give higher temperature levels at the upper part of the bed , which is the desired objective, but also lower at its bottom.
- **The 40%/60% ratio gives the most uniform profile overall.**
- As the percentage of secondary fuel is increased, lower heat is transferred to the cooling lances, which could be desirable for achievable lower technical minimum load

CERTH – PROCESS MODELING – CONCLUSIONS

- There is a fair agreement between the results of the simulations and those of the experiments.
- TES idea results in lower temperature differences between the loads. In addition, ramp up and down occurs faster compared to the case without TES, equal to ~4.8 and ~2 times, respectively. This is only attributed to the sensible heat added/removed since no unburned char is present in the entrainment.
- The fuel staging system at 3m and with primary/secondary fuel ratio equal to 40%/60% gave higher temperature levels at the upper part of the bed compared to the reference case, which is beneficial for the technical minimum operation of the bed (lower thermal stresses and reduction of NOx).
- The CFB model along with the examined concepts has been utilized to model a complete **CFB power plant**, which, however, cannot be presented due to confidentiality issues.

Publication: D. Stefanitsis, A. Nesiadis, K. Koutita, A. Nikolopoulos, N. Nikolopoulos, J. Peters, J. Ströhle and B. Epple, “Simulation of a CFB Boiler Integrated With a Thermal Energy Storage System During Transient Operation”

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