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From innovation to operational assistance

CFD modeling of Electrabel boilers in the framework of increased biomass co-firing

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Situation within Electrabel

- Increased biomass co-firing in PC-fired plants
  - Gelderland 13: + 8 PJ/y wood
  - Polaniec: agricultural biomass (straw) + wood
  - Rodenhuize 4: “Advanced Green”
    may be “Max Green” (200 MW_e)
- Issues
  - Boiler not designed for biomass
  - Other physical and chemical characteristics “coal ↔ biomass”
  - Some biomass contain critical elements (alkali, chlorine, phosphor)
  - Sometimes: also burner and boiler modifications necessary
- Possible consequences
  - Other combustion profile
  - Increased slagging, fouling and corrosion risks

Possible problems and how to predict them

- Possible combustion problems
  - Higher heat fluxes
  - Higher unburned carbon and CO formation
    - CO near water walls is dangerous CO → corrosion risk
  - Other T profile in combustion chamber
  - Increased NO_x
  - Disturbed water – steam circulation

- Tools
  - CFD is a powerful tool for prediction of former parameters
  - CFD's were performed by RECOM (Stuttgart) in collaboration with Laborelec
  - <u>Important</u>
    - CFD can detect slagging and corrosion sensitive areas → particle path, CO rich and O_2 lean areas, …
    - But CFD has its limitations → see next slide

About CFD - Limitations

- CFD cannot predict:
  - Long-term effects
  - Nature of slagging: crystalline, amorphous, chemical composition?
  - Corrosion: type of corrosion and corrosion rate

    → Other tools are more recommended
- Boundary conditions need to be OK
- Very detailed and exact input required
  - Design data
  - Operational data
  - Especially burner details are important
- If boundary conditions and input are wrong or not enough detailed:
  - False conclusions
  - Calculated values ≠ Real operational values
- Sometimes large error margins, for example NO_x : +/- 30% (Recom)
- Pyrolysis behavior of biomass fuels: differences ?

Power plants: main issues to investigate by CFD

- Gelderland 13 → Increased wood co-firing
  - Combustion at very low load
- Polaniec → wood + straw
  - Influence of straw combustion
  - CO – waterwall corrosion
  - Burn out
  - NO_x formation
  - T exit combustion chamber
- Rodenhuize 4 (“Max Green”) → 200 MW_e wood
  - Heat fluxes
  - Burn out and CO
  - NO_x
  - T exit combustion chamber

G13 – Partial load 100% coal - Results

	Measurement 25.01.2008 03:00 – 05:00	Baseline Simulation 2 100% coal - P
NOx [mg/Nm^3,@ 6% O_2]	530 (479 – 620)	470
CO [mg/Nm^3,@ 6% O_2]	23 (0 – 55)	8
Unburned Carbon in Fly Ash [%]	*	0.5
Averaged Fluegas Temperature at the Level of the Nose (59.1 m) [°C]	-	1146 (max 1318)

* Daily measurements of unburned carbon in fly ash were only available for February and March.

The values for February range from 0.6 % – 5.7 % (average 3.8 %).

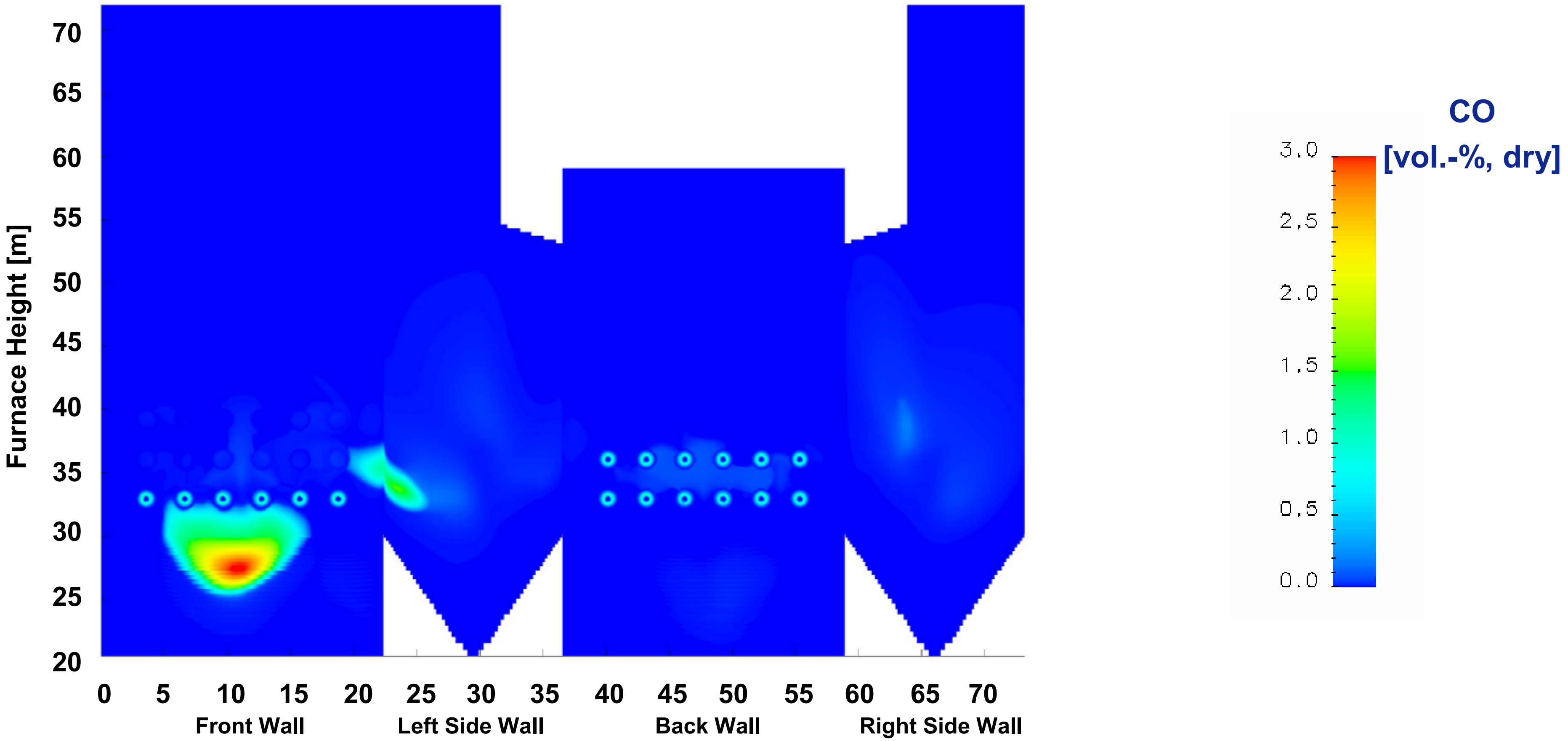
2 measurements for unburned carbon in bottomash were available: 7.93 % in January and 4.93 % in February.

G13 – Partial load 100% coal - Summary

- The simulation results show reasonable good agreements with the measured furnace exit values of NO_x, CO and unburned carbon in ash.

- The simulation results show
  - An O_2-rich and CO-lean wall atmosphere at most of the evaporator wall
  - Some regions of O_2-lean regions are visible in the ash hopper area below the first burner level.
  - In these regions higher CO concentrations can be observed in the model → See next slide

G13 – Partial Load 100% coal - CO on Furnace Walls



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G13 – Partial Load with wood - Results

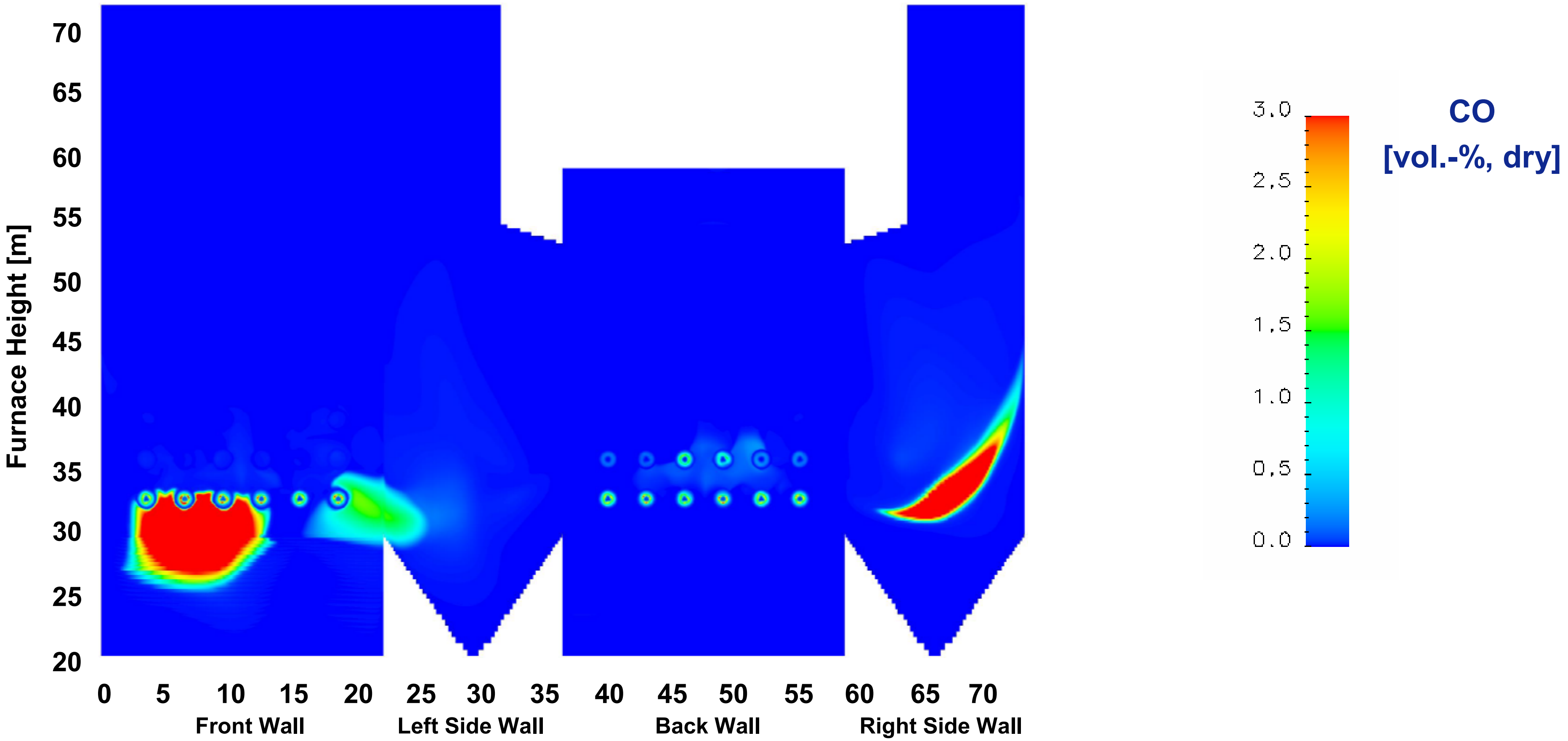
Comparison of furnace exit values

	Baseline Simulation 2 Partial load 100% coal	Variation Partial load with wood
NOx [mg/Nm^3,@ 6% O_2]	**470**	**539**
CO [mg/Nm^3,@ 6% O_2]	**8**	**8**
Unburned Carbon in Fly Ash [%]	**0.5**	**0.5**
Averaged Fluegas Temperature at the Level of the Nose (59.1 m) [°C]	**1146** **(max 1318)**	**1134** **(max 1332)**

G13 – Partial Load with wood - Summary

- The calculated CO emission and unburned carbon in ash of variation 2 is comparable to the simulation results of baseline 2
- Some higher CO on the furnace walls is observed
- The calculated NO_x emission for variation 1 is about 69 mg/Nm³ higher than for the baseline simulation 2. A reason for this increase could be the outer burners of burner level 3 which are showing a jet burner pattern.
- The simulated wall oxygen coverage of variation 2 is comparable to the results of the baseline simulation 2.

G13 – Partial load with wood - CO on Furnace Walls



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Polaniec – Influence of straw – 85 % coal + 15% straw

Computed Furnace Exit Values

<table>
<tr><th></th><th>Baseline</th><th colspan="2">Scenario
85 % coal + 15% straw</th></tr>
<tr><td>Averaged Fluegas Temperature at the Level of the Nose (40.7 m) [°C]</td><td>1273 (max 1414)</td><td colspan="2">1266 (max 1404)</td></tr>
<tr><td>NO_x [mg/Nm^3,@ 6% O_2]</td><td>468</td><td colspan="2">439</td></tr>
<tr><td>CO [mg/Nm^3,@ 6% O_2]</td><td>16</td><td colspan="2">15</td></tr>
<tr><td rowspan="3">Unburned Carbon in Fly Ash [%]</td><td rowspan="3">2.5</td><td rowspan="3">3.2</td><td>2.5 % from coal</td></tr>
<tr><td>0.0 % from wood</td></tr>
<tr><td>0.7 % from straw</td></tr>
</table>

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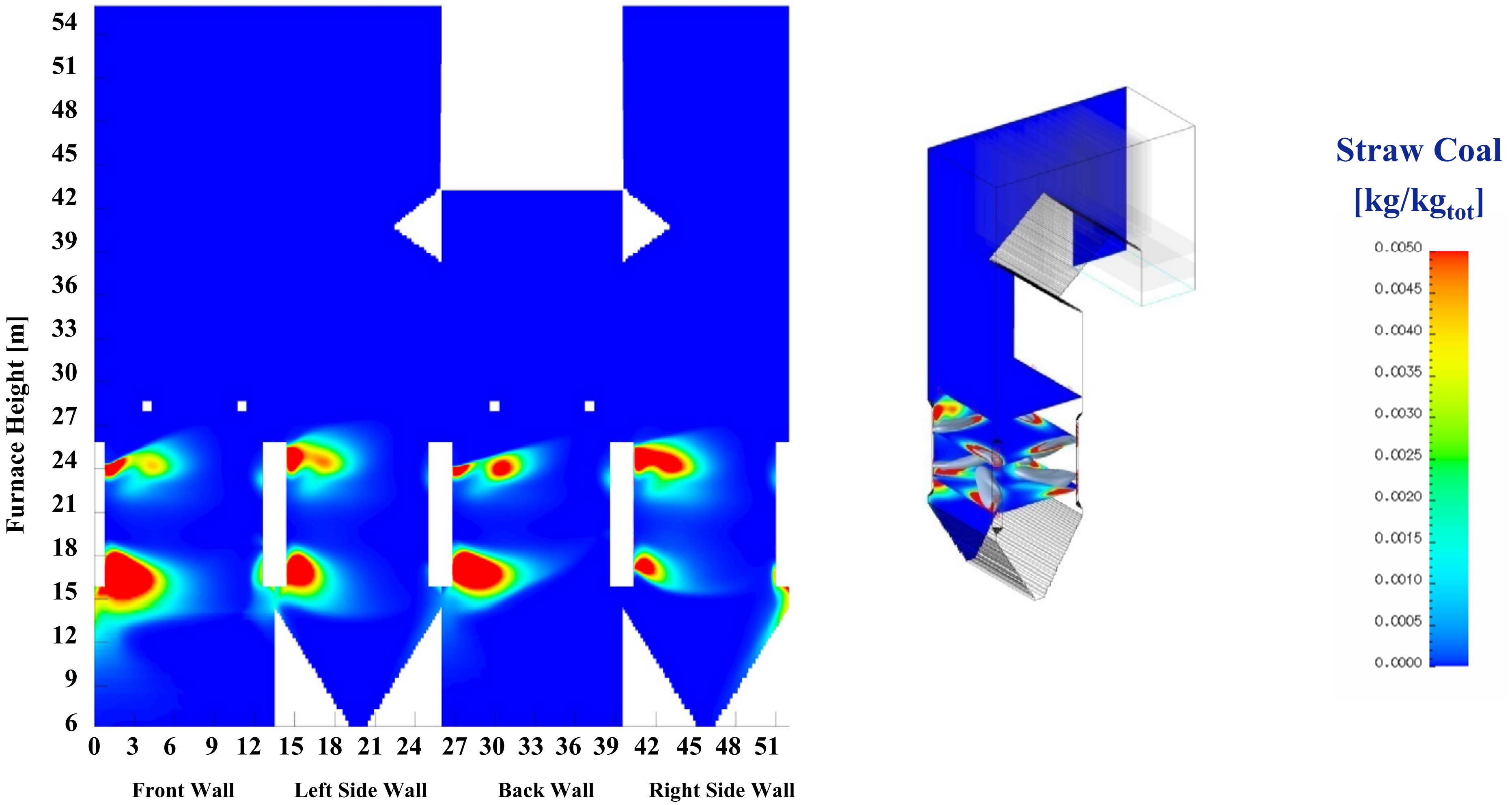
Polaniec – Influence of straw – 85 % coal + straw

Summary

- The simulation results show an increase of the unburned carbon in ash value compared to the baseline simulation. This is mainly attributed to the slow pyrolysis rate of the straw particles. The CO emission although is comparable to the baseline simulation.
- A slight NO_x reduction can be observed in the model when compared to the baseline simulation.
- The simulation results indicate an O_2-rich and CO-lean wall atmosphere at most of the Evaporator and Superheater (SH 1) tubes. Small spots of O_2-lean regions are visible in the burnerbelt, but still all evaporator tubes are covered with at least 0.5 vol.-% of oxygen in the model.
- The simulation results show some spots with a high amount of straw particles in the burner belt. The reason is probably the slower pyrolysis rate of the straw particles when compared to coal and the fact, that all straw is fired on two mills only, leading to a higher straw concentration at this location. These high straw concentrations on the furnace walls could lead to a higher slagging potential → see next slide

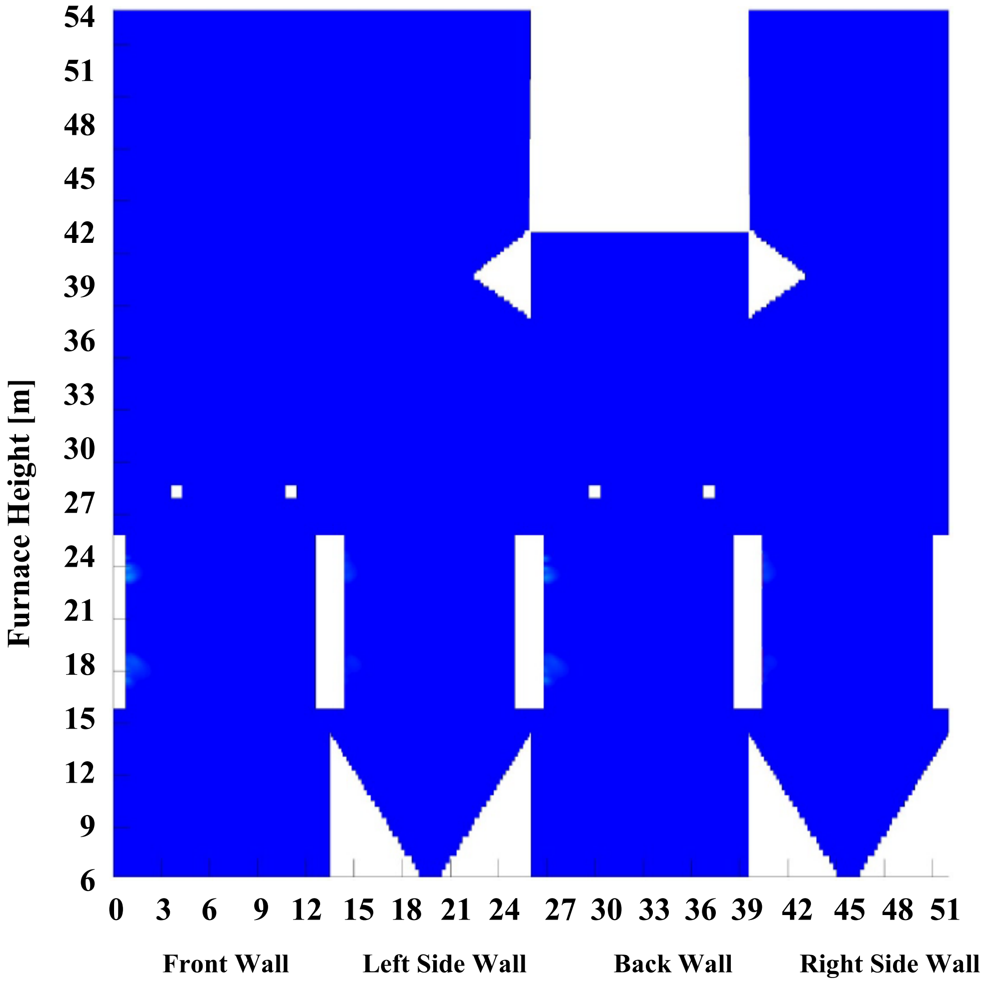
Polaniec – Influence of straw – 85 % coal + 15% straw

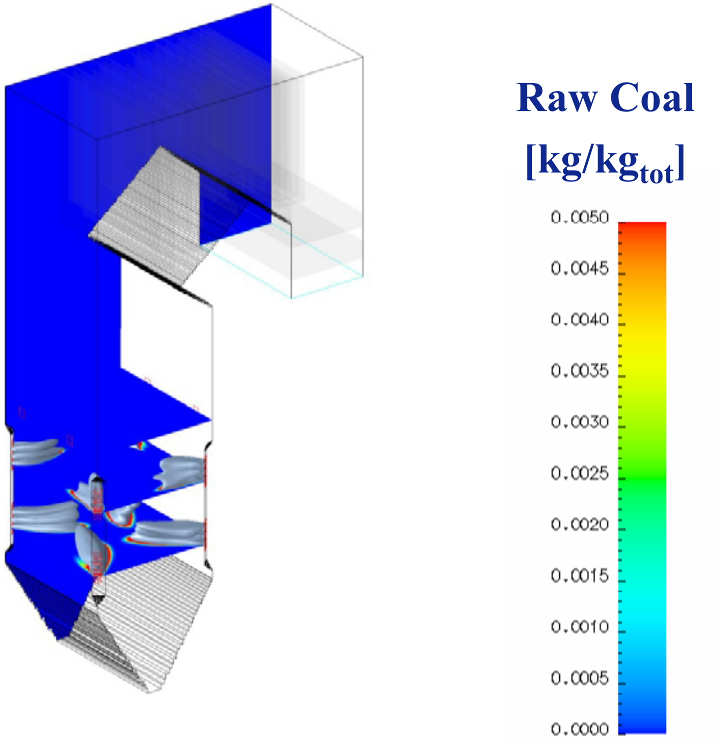
Straw on Furnace Walls and Isosurface 0.05 kg/kg_{tot}



Polaniec – Influence of straw – 100% coal

Raw Coal on Furnace Walls and Isosurface 0.05 kg/kg$_{tot}$





Rodenhuize 4 – 200 MW_e wood

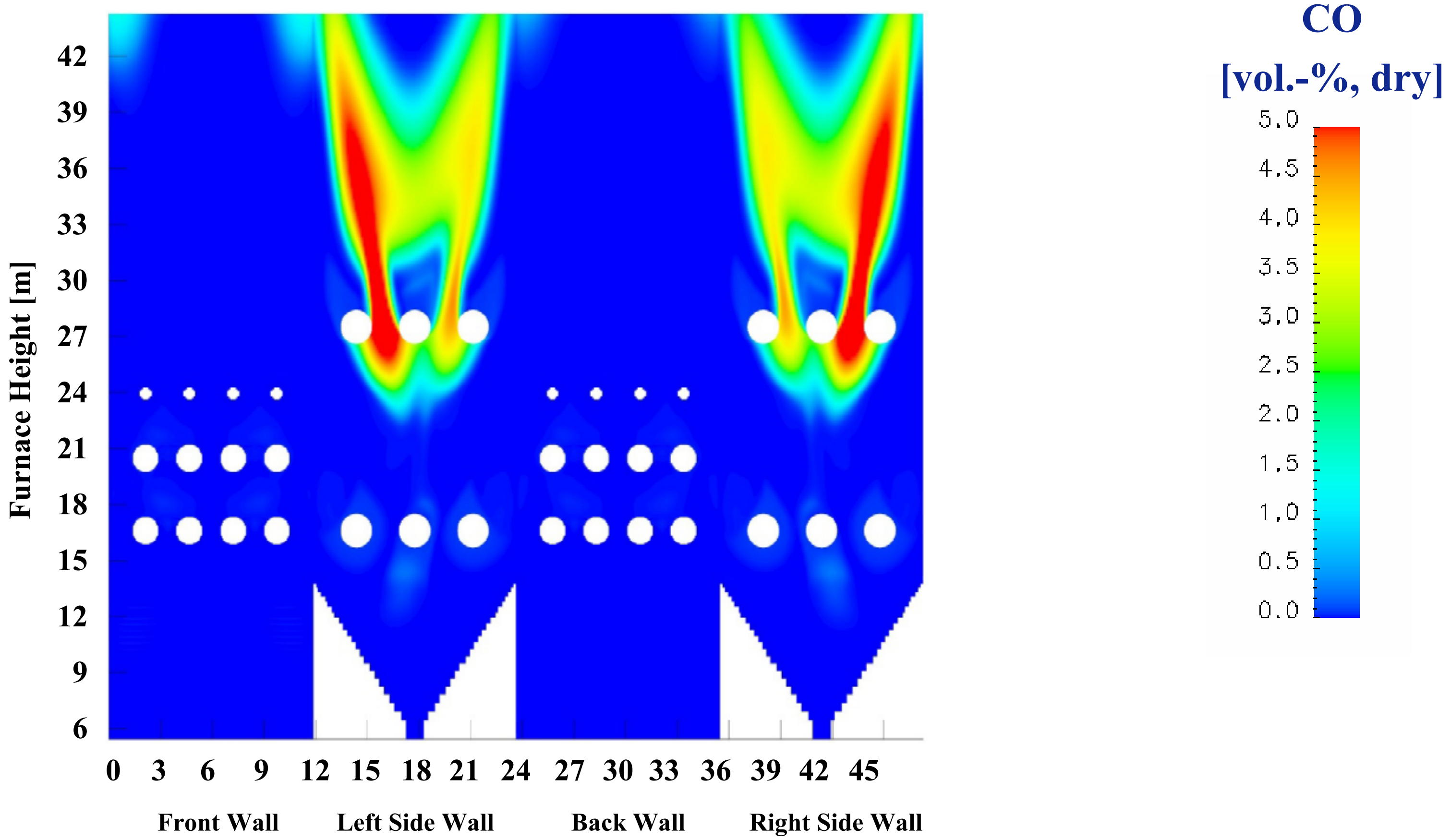
Computed Furnace Exit Values

	Simulation
Furnace Exit Temperature [°C]	**1084 (max 1168)**
NOx [mg/Nm^3,@ 0% O_2]	**270**
CO [mg/Nm^3,@ 0% O_2]	**893**
Unburned Carbon in Fly Ash [%]	**41.3**

Rodenhuize 4 – 200 MW_e wood – Summary

- The 65 MW_e load simulation results show a higher NO_x emission compared to the 200 MW_e load simulation. This can be attributed to a significantly lower excess oxygen level (3.0 vol.-%, dry) and lower temperature peaks compared to the 65 MWe load case.
- The model predicts a CO emission of 893 mg/Nm^3 at 0% O_2 and a unburned carbon value of 41.3 %. High CO concentrations are mainly located close to the sidewalls (see CO-isosurface plot). This could be attributed to the poor mixing of the outer overfire air jets.
- The model results indicate an increased amount of evaporator surface (sidewalls) that is covered with an oxygen lean atmosphere and high CO concentrations. This indicates an increased corrosion risk.
- In order to reduce unburned carbon and CO emissions, a better mixing can be achieved by optimizing the momentum of the overfire air.
- Another possibility would be to operate some of the blast furnace gas burners out of service at level 3 with air instead of recirculated flue gas

Rodenhuize 4 – 200 MW$_e$ wood – CO on Furnace Walls



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Conclusions

- CFD is a helpful tool in predicting combustion behavior and possible problems in case of:
  - Boiler or burner modifications
  - Fuel change
  - Modification of operating parameters

- However, it remains a “tool”
  - Not everything can be predicted, for example nature of slagging and corrosion
  - Boundary conditions → exact
  - Input of design and operational data → very detailed and exact
  - Sometimes large error margins, for example NO_x : +/- 30%
  - Sometimes assumptions are made (pyrolysis behavior)

Five reasons for you to choose Laborelec :

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- You benefit from independent and confidential advice
- You are supported by a recognized and accredited laboratory

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