Business from technology

Time-averaged simulation of the furnace of a Chinese 135MWe CFB Boiler

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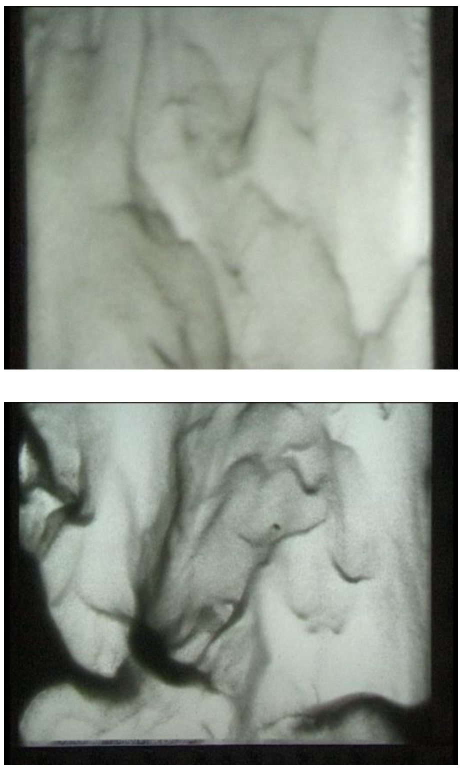
Contents

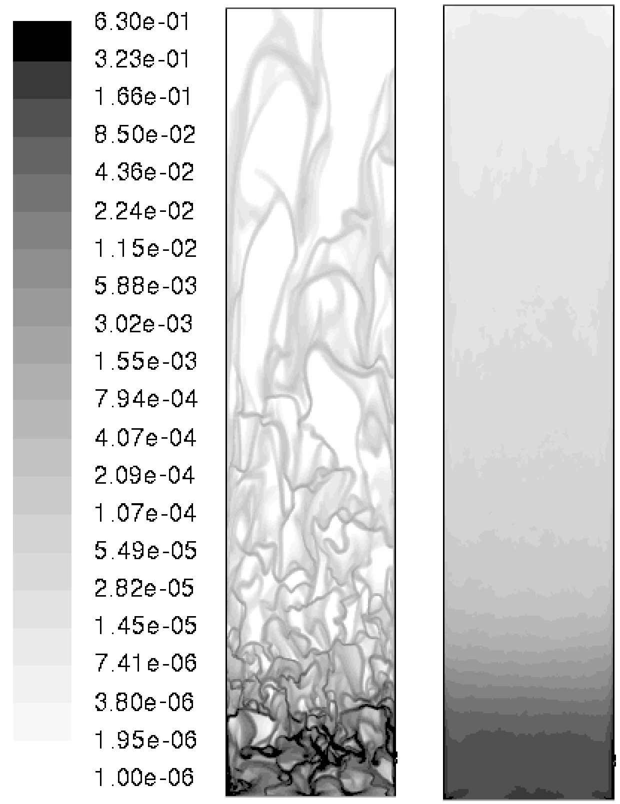
Introduction - Characteristics of CFB hydrodynamics

Gas-solid flow in fluidized beds is dominated by fluctuations of velocities, solids concentration and chemical components.
→ The effects of these **fluctuations have to be included in the model!**

Video images from a 0.4 m wide pseudo 2D CFB at Åbo Akademi.



Instantaneous and average solids volume fraction in a 2D simulation of a 1 m wide CFB riser.



Introduction - Modeling alternatives 1

Transient Eulerian-Eulerian modeling

- Continuum description of gas and solids
- Benefits:
  - kinetic theory models fairly accurate and validated in small scale
- Drawbacks:
  - Requires either a fine mesh or rigorous mesh-size-dependent closures to account for the fine flow structures
  - No general mesh-dependent closures available so far; gas-solid drag force correlations have been suggested (e.g. EMMS)
  - Complicated to describe distributions of particle properties
- Available in several CFD codes
  - Ansys Fluent, MFiX, OpenFOAM…

Introduction - Modeling alternatives 2

MP-PIC (Multi-Phase Particle-in-Cell)

- Tracks parcels of particles
- Combines an Eulerian solids description with Lagrangian solids tracking
- Benefits:
  - Good description of particle properties (distributions of size, composition, etc.)
- Drawbacks:
  - Requires either a fine mesh or rigorous mesh-size-dependent closures to account for the fine flow structures
  - No general mesh-dependent closures available so far; gas-solid drag force correlations have been suggested (e.g. EMMS)
- Available in Ansys Fluent and Barracuda

Introduction - Modeling alternatives 3

Macroscopic modeling

- 3D balance equations combined with empirical correlations for solids distribution
- Benefits
  - Fast simulation
  - Can utilize measurement data
- Drawbacks
  - Ability to account for geometrical details
  - Relies heavily on experimental correlations; may not react correctly to changes in process conditions
- Available in in-house codes (LUT, Hamburg-Harburg, Chalmers)

Introduction - Modeling alternatives 4

Time-averaged Eulerian-Eulerian CFD modeling

- Steady state continuum description of gas and solids
- Equations are based on time-averaging the transient Eulerian- Eulerian equations
- Benefits
  - Fast simulation (no need to time-average the results)
  - Should react correctly to process changes since the equations are based on transient CFD models
- Drawbacks
  - Difficulties in accounting for distributions of particle properties
  - Rigorous closures required but nor yet commonly available
  - Increased reliance on closure model compared to transient CFD
- Available as in-house implementations (e.g. VTT, Tsinghua)

Description of the time-averaged CFD model

Gas and solids momentum

- Closures for **drag**, **Reynolds stresses**, **volume fraction-pressure correlation** and **solids pressure** terms.

Turbulence, Reynolds stresses

- **Transport equations** are solved **for the solids phase components** of velocity correlations (xx,yy,zz,xy,xz,yz) .
- **Gas phase** stresses are calculated **with algebraic correlations** from the solid phase stresses.
- Fluctuation **time scales** are obtained from **algebraic correlations.**
- Small scale and dilute turbulence: dispersed *k*-*ε* model with a modified turbulent viscosity

Description of the CFD Model

Energy: Specific enthalphy equations for both phases

- **Isotropic diffusion** coefficient approximated **from Reynolds stresses and time scales**
- **Phase interaction** (Gunn, 1978), **wall heat transfer** based on: Vijay& Reddy (2005)

Species equations for gas components

- **Isotropic diffusion** coefficient approximated **from Reynolds stresses and time scales**.
- Gas **reactions** are assumed to be **limited by mixing.**
- **Species**: O_2, N_2, CO_2, CO, H_2O, H_2 and CH_xO_y.
- **Reactions**:

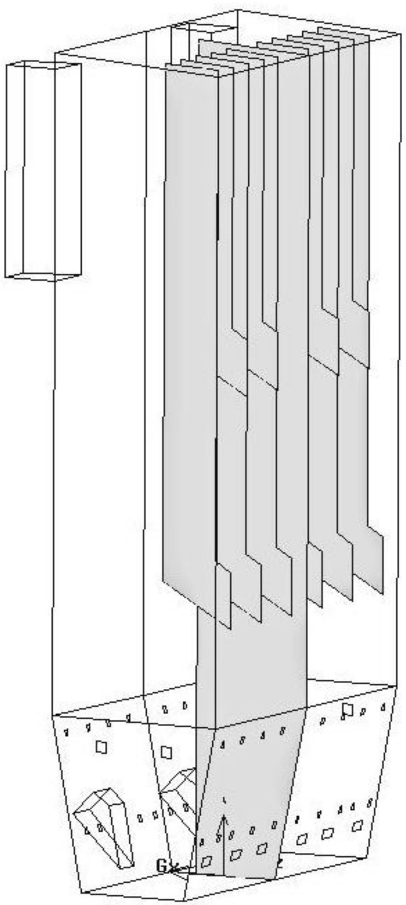
1. $CH_xO_y+(x/2+1-y)/2\ O_2 \rightarrow CO + x/2\ H_2O$
2. $CO + 0.5\ O_2 \rightarrow CO_2$
3. $H_2 + 0.5\ O_2 \rightarrow H_2O$

Description of the CFD Model

Fuel particles: modelled with a **Lagrangian approach**

- **Coupled to** velocities and velocity fluctuations of **both phases**.
- Recirculation of fuel particles.
- Closures:
  1. **Heat transfer**: Palchonok (1998)
  2. **Drying**: constant particle size
  3. **Devolatilization**: Ross et al. (2000), single volatile species (CH_xO_y), constant particle size
  4. **Oxidation**: shrinking particle model, internal and external mass transfer, chemical kinetic inside the char particle. Kinetic parameters based on the results of Konttinen et al. (2002).

The 135 MWe CFB boiler in Ruzhou, China



- Furnace to large extent split to two halves by a membrane wall.
- Secondary airs at two heights on the front and back walls.
- Six coal feeders on the front side.
- Burns a local high ash coal.

Fuel analysis:

Size, mm	0.0 - 0.5	0.5 – 1.0	1.0 – 2.0	2.0 - 3.2	3.2 – 6.0	> 6.0
%	31.2	16.2	26.3	11.1	8.5	6.7

Volatiles [wt% daf]		Proximate [wt% a.r.]				Ultimate [wt% daf]				
		Comb.	Ash	Moist.		C	H	O	S	N
41.7		32.6	62.6	4.8		56.9	7.7	32.1	1.8	1.6

Simulated cases

- Two cases were simulated to evaluete the model’s capabilities to react to changes in the process conditions
- Measured median diameter of solids at 17.9 m and 27.4 m heights:
  - 80 MWe: 91 μm, 74 μm
  - 120 MWe: 116 μm, 95 μm

High load 120 MWe

Air flow	Primary	To coal feeders	To ash coolers	To loop seal		Upper secondary		Lower secondary	
				Left	Right	Left	Right	Left	Right
kg/s	46.5	4.7	10.7	0.34	0.35	21.7	9.2	19.1	11.0

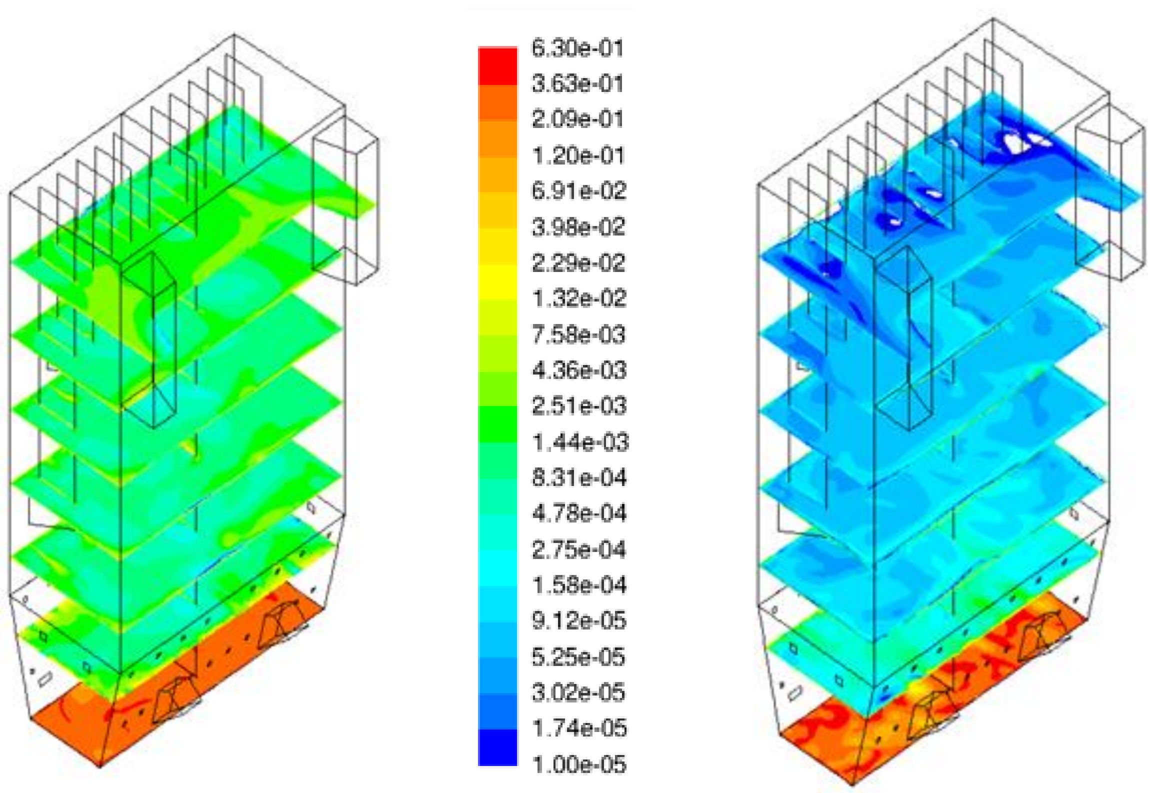
Fuel flow	Feeder 1	Feeder 2	Feeder 3	Feeder 4	Feeder 5	Feeder 6
kg/s	6.3	7.9	8.1	7.9	4.0	3.0

Low load 80 MWe

Air flow	Primary	To coal feeders	To ash coolers	To loop seal		Upper secondary		Lower secondary	
				Left	Right	Left	Right	Left	Right
kg/s	38.2	4.3	11.3	0.37	0.36	14.8	14.9	8.2	10.3

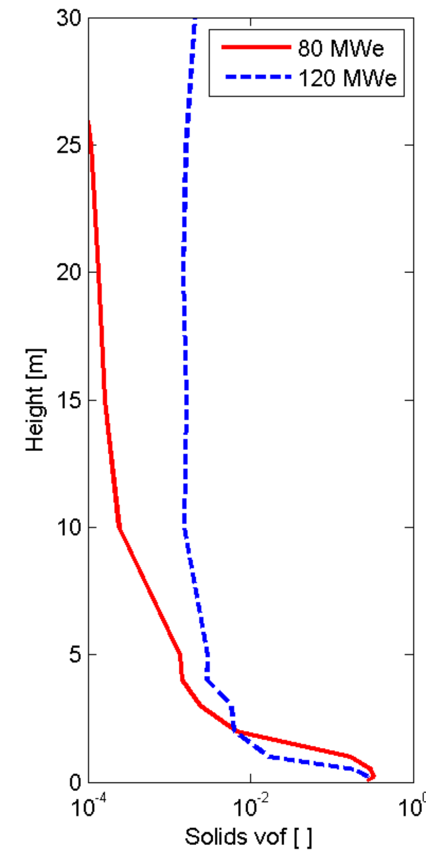
Fuel flow	Feeder 1	Feeder 2	Feeder 3	Feeder 4	Feeder 5	Feeder 6
kg/s	1.4	5.7	3.9	6.7	3.1	1.2

Results: Solids volume fraction



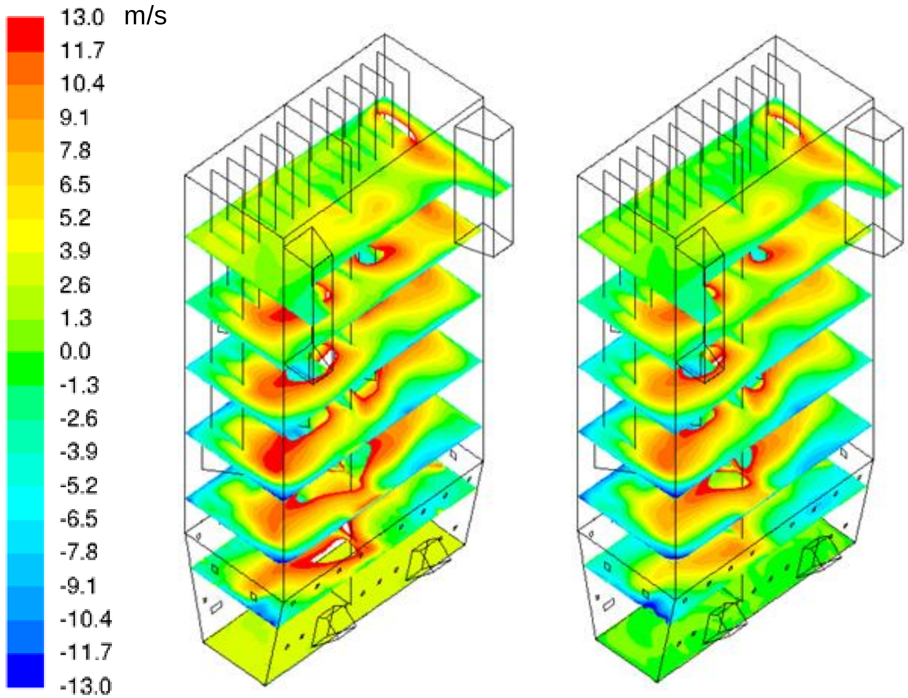
120 MWe

80 MWe



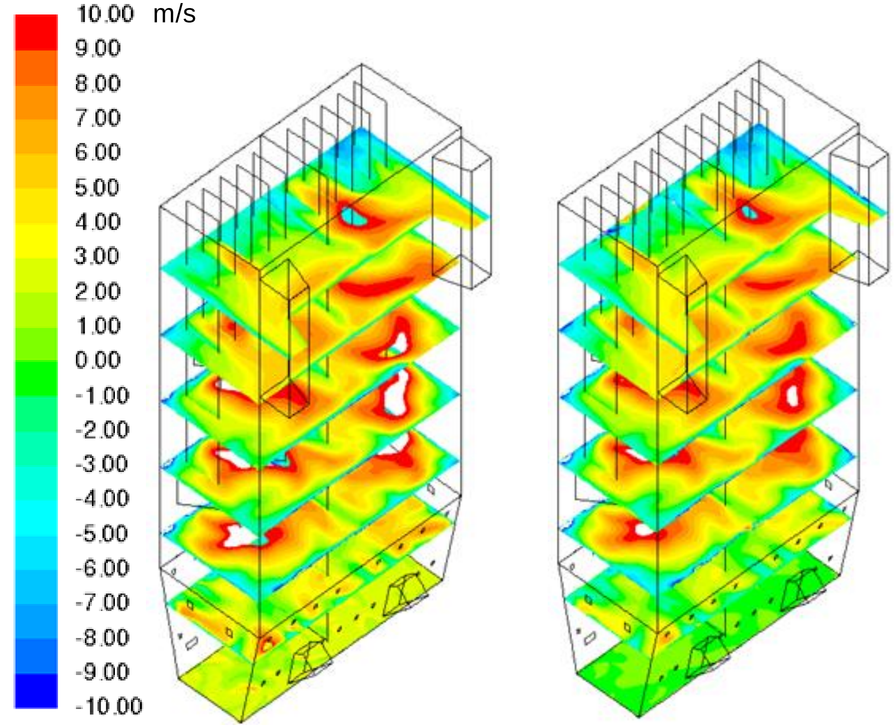
Results: Vertical velocities

120 MWe



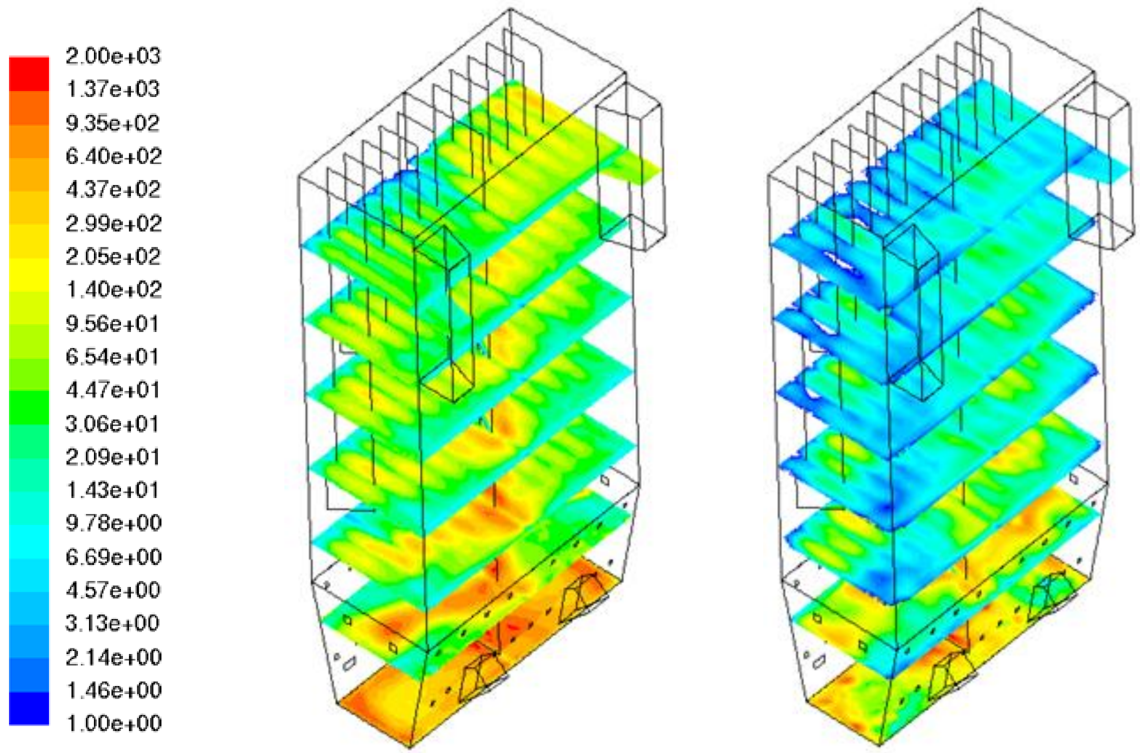
Gas Solids

80 MWe



Gas Solids

Results: Heat sources



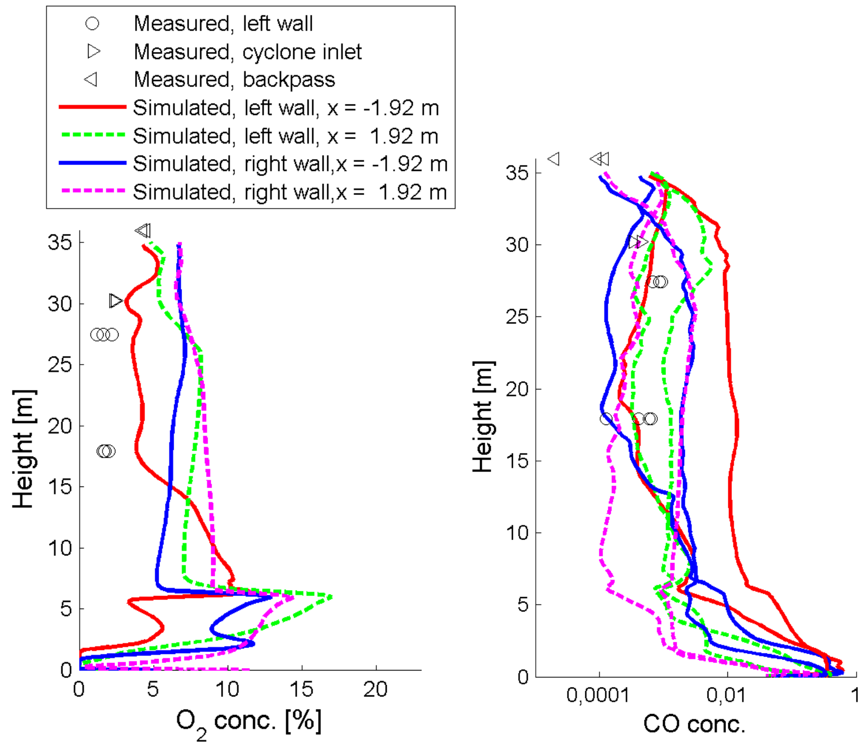
120 MWe

80 MWe

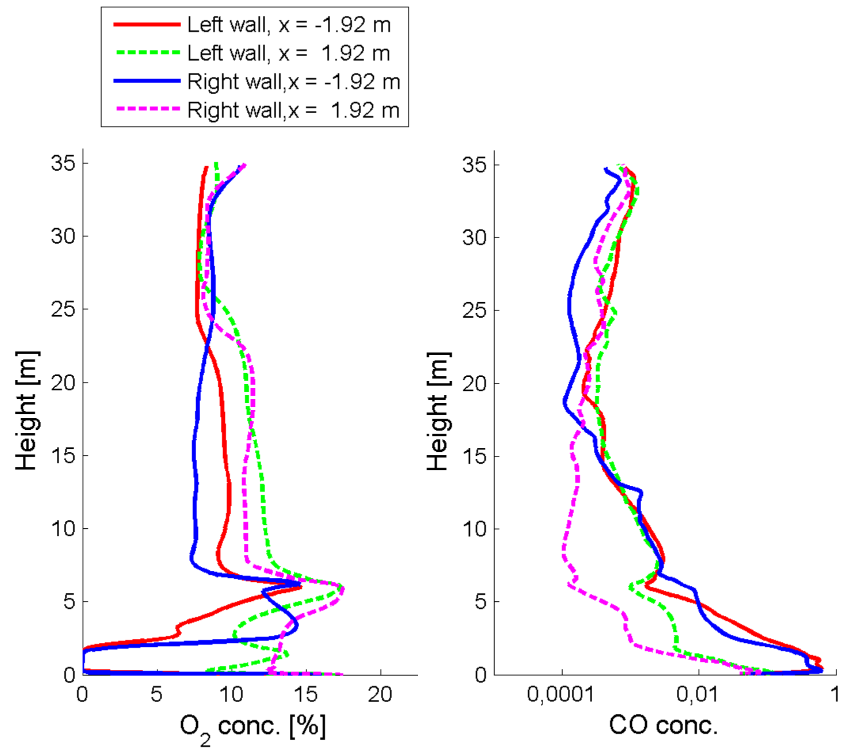
Heat source in a computational element.

Results: Chemical composition

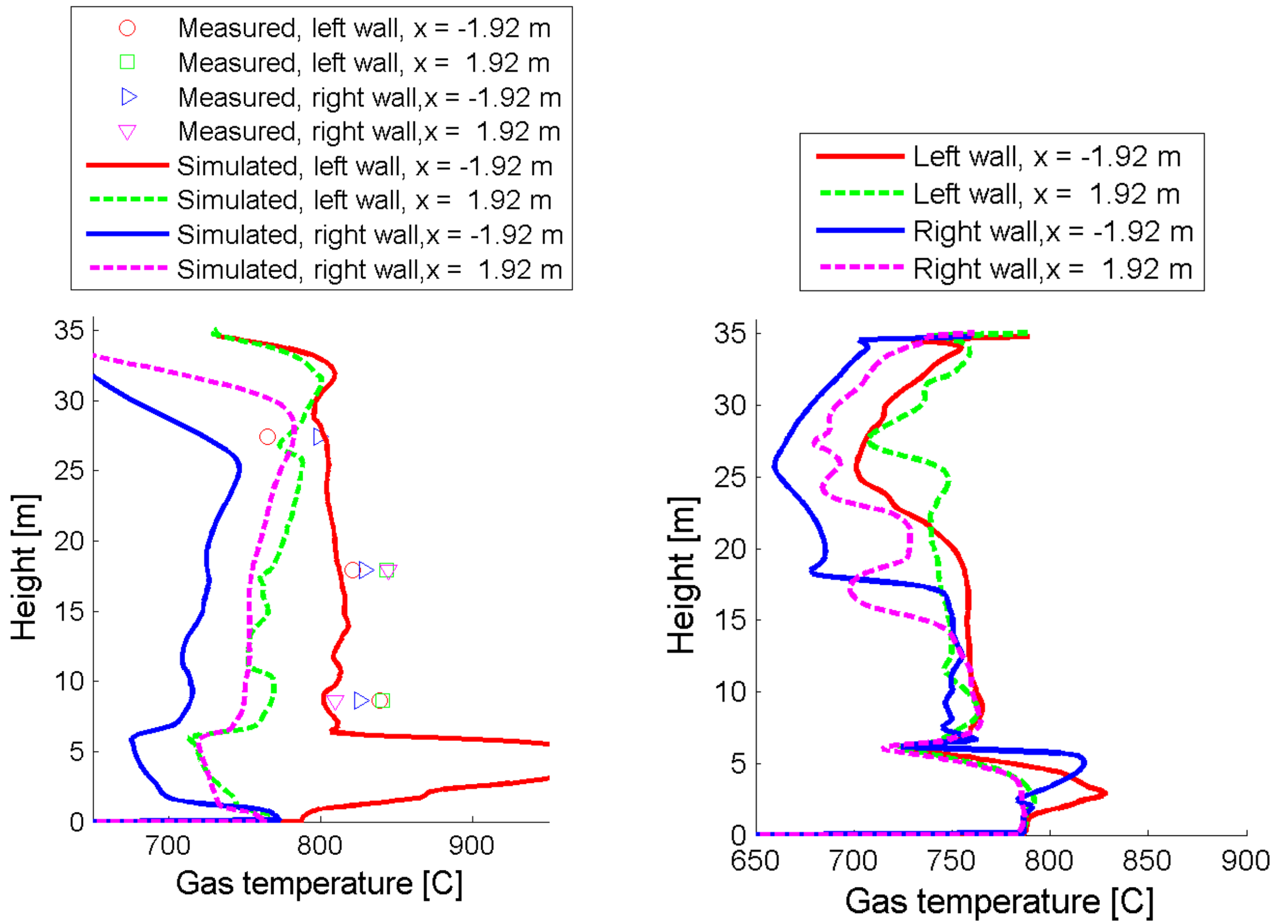
120MW



80MW



Results: Temperature in the vicinity of left side wall



120 MWe

80 MWe

Conclusions

- Simulation results show typical characteristics of a CFB: dense bottom and wall layers, down flow at walls.
- The low O_2 concentration region below the secondary air feed level, is well produced by the simulations.
- The simulations are clearly sensitive to changes in process conditions.
- Because of the long fuel residence times, iterating the Eulerian simulation and the Lagrangian simulations of the fuel particles proved very time consuming in a large boiler.
- Present model closures were not derived to cover for the unusually fine bed particles of this boiler.
- These shortcomings are addressed in the research efforts made presently by the authors and thus even better results are expected in the future.

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