‘CFD based modelling of a large-scale power plant for co-combustion of biomass gas and pulverised coal. Case: Kymijärvi power plant in Lahti, Finland.’

Subtask 3.3

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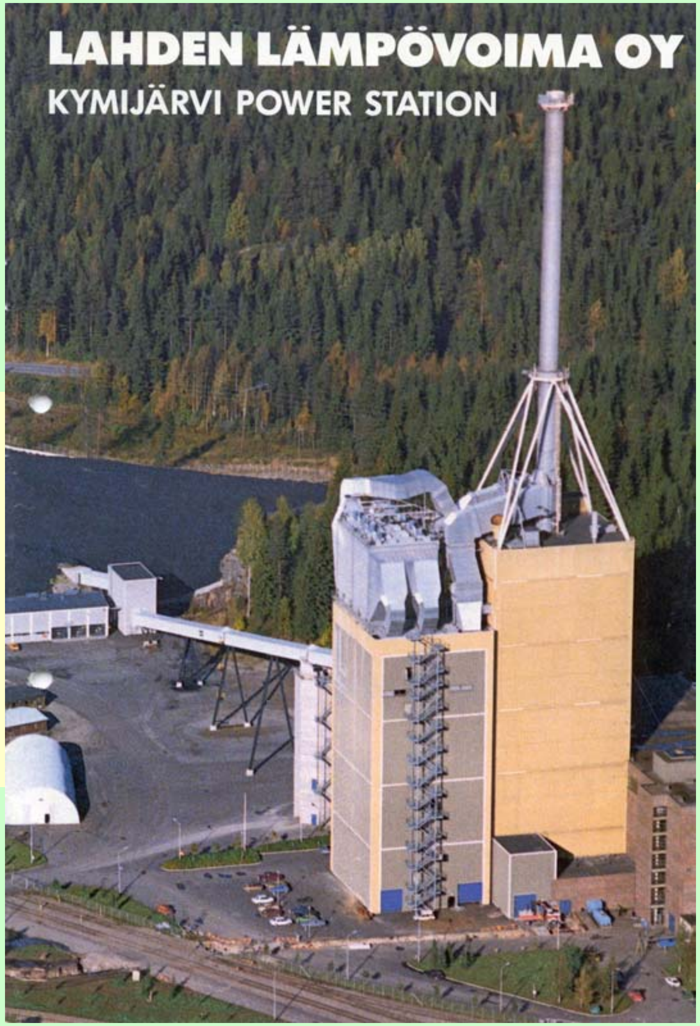
Presentation layout

1. Background
2. Objectives of the work
3. Modelling approach
4. Cases studied
5. Results
6. Conclusion

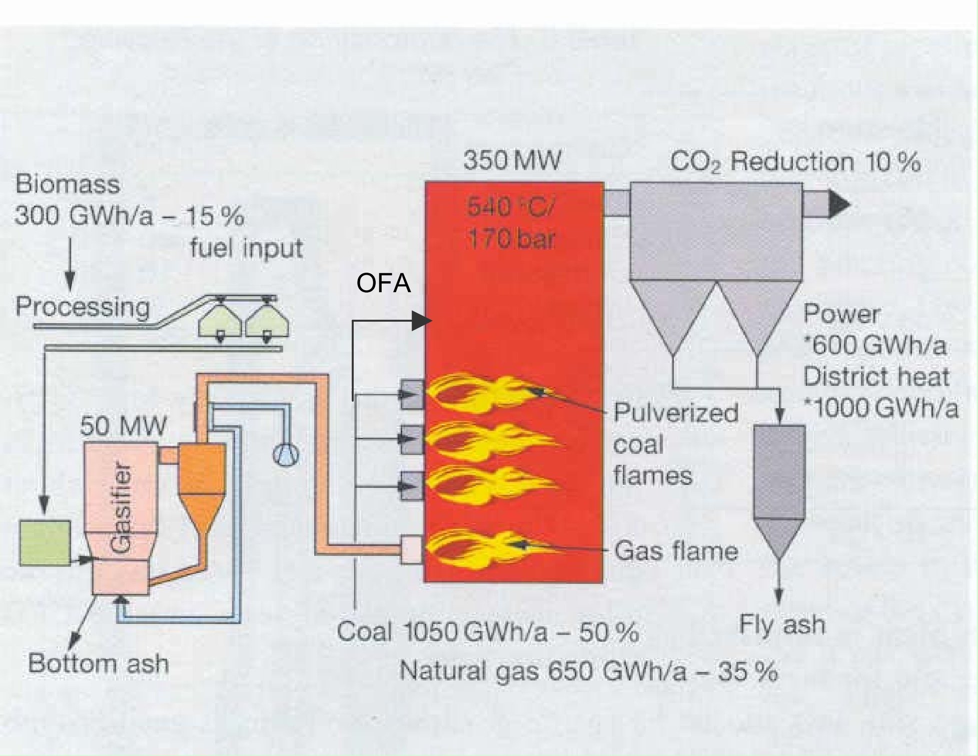
1. Background

- Co-combustion of biomass based gasification gas and pulverised coal
- 167 MW_e and 240 MW district heat
- NO_x emissions today 200-240 mg/MJ
- Current NO_X emission limit 230 mg/MJ. Future limits?



The boiler at the Kymijärvi power plant

- Benson, once-through boiler, max 350 MW
- 8 low-NO_x and 4 conventional burners for coal, Σ 300 MW
- 2 gas burners, Σ 50 MW
- Over-fire air (OFA)



Boiler data

Height: 50 meters

Base: 10 x 7 meters

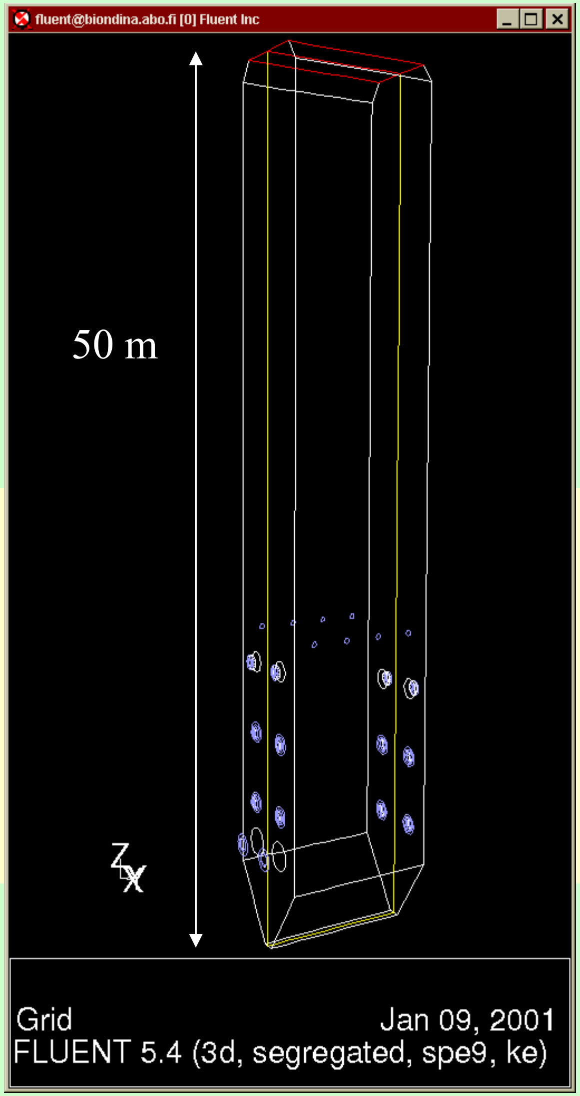
Gas burners, level 0

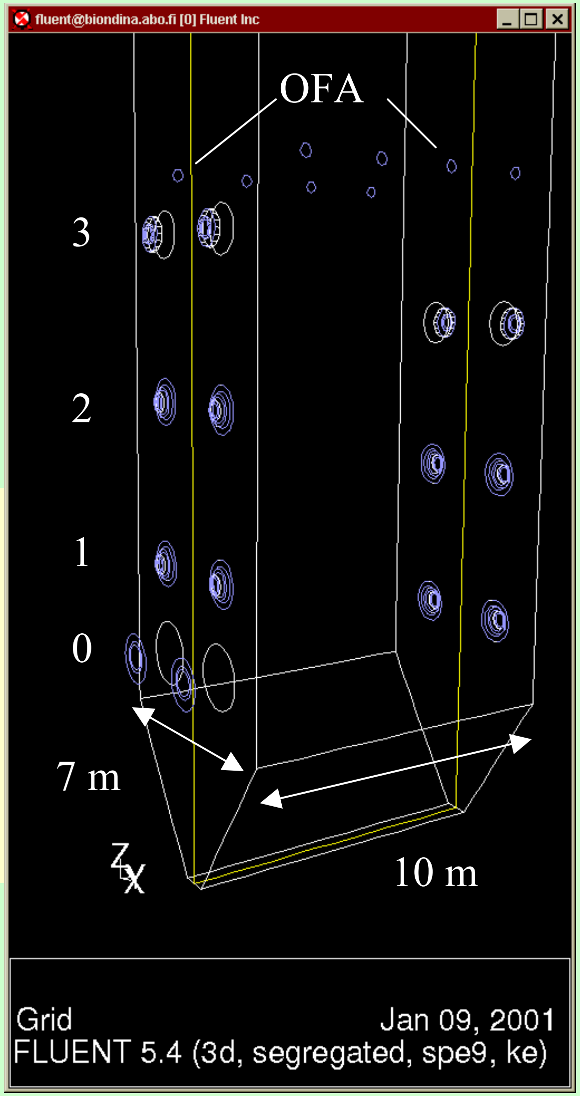
Low-NO_X burners, level 1&2

Conventional burners, level 3

Over-fire air, above level 3

12 + 2 = Σ 14 burners





2. Objectives of the work

- Better insight into temperature- and flow fields as well as concentration profiles for all major chemical species inside the main boiler under different operating conditions.

- First step towards a better understanding of how, where, and why NO_x is formed in the boiler.

Slagging problems (cont.)

Gas burner

Low-NO_X burner

3. Modelling approach

- Commercial CFD software, FLUENT® version 5
- State-of-the-art submodels in FLUENT® 5
- Boundary conditions
  - air flows, fuel data, coal properties

Submodels used

- *k-ε* turbulence model
- Coal Combustion
  - *Constant devolatilisation rate* model
  - *Kinetics/Diffusion* limited char combustion

    $C(s) + O_2 \rightarrow CO_2$
- *Discrete Ordinates Method* for radiation
- *EDCM/Finite Rate* for gas-phase combustion
  - species considered: O_2, CH_4, CO, CO_2, H_2, H_2O

Gas-phase combustion

Reactions considered:

$CH_4 + 1/2O_2 \rightarrow 2\ H_2 + CO$

$CH_4 + H_2O \rightarrow 3H_2 + CO$

$H_2 + 1/2O_2 \rightarrow H_2O$

$CO + H_2O \leftrightarrow CO_2 + H_2$

(Jones&Lindstedt, 1988)

Reactions limited either by:

- mixing (EDCM) or
- kinetics (Finite Rate)

Combined EDCM/Finite Rate ⇒ *both* kinetics *and* mixing controlled

$$r = \min(r_{EDCM}, r_{FINITE\ RATE})$$

Boundary conditions

FUELS

- Medium volatile coal
  - detailed data not available

- Gasification gas (vol-%)
  - CO_2 12.9
  - CO 4.6
  - H_2 5.9
  - CH_4 3.4
  - H_2O 33.0
  - N_2 40.2

AIR FLOWS

Burner air staging + over-fire air

- λ = 0.93-0.97 at coal burners
- λ = 1 at gas burners
- Adding OFA gives overall stoichiometric air-fuel ratio ~ 1.2

4. Cases studied

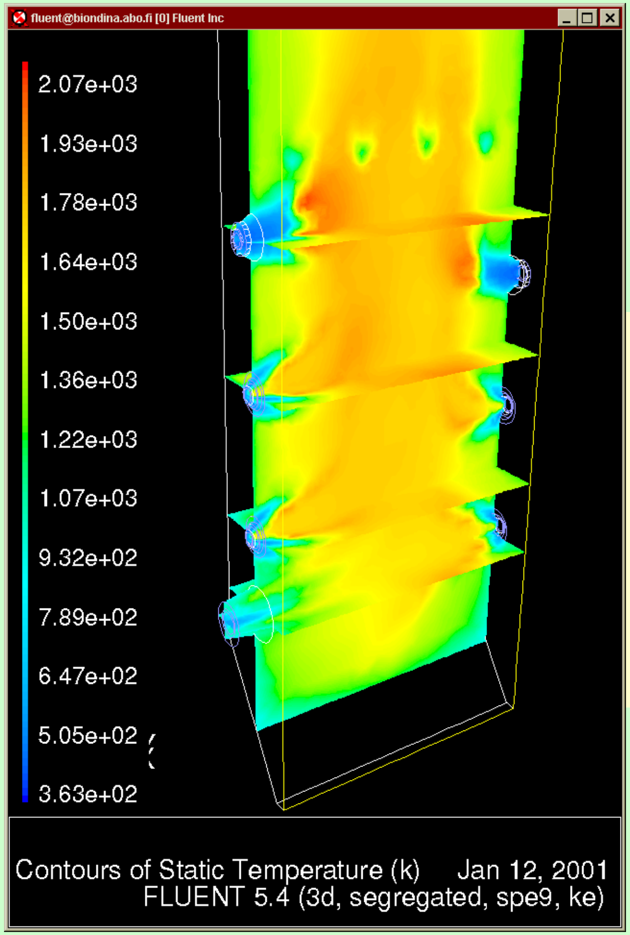
- *Case I*
  - Full load on all coal and gas burners.
- *Case II*
  - Coal load 60 % on level 1 burners.
- *Case III*
  - Gasification gas load 50 %

5. Results

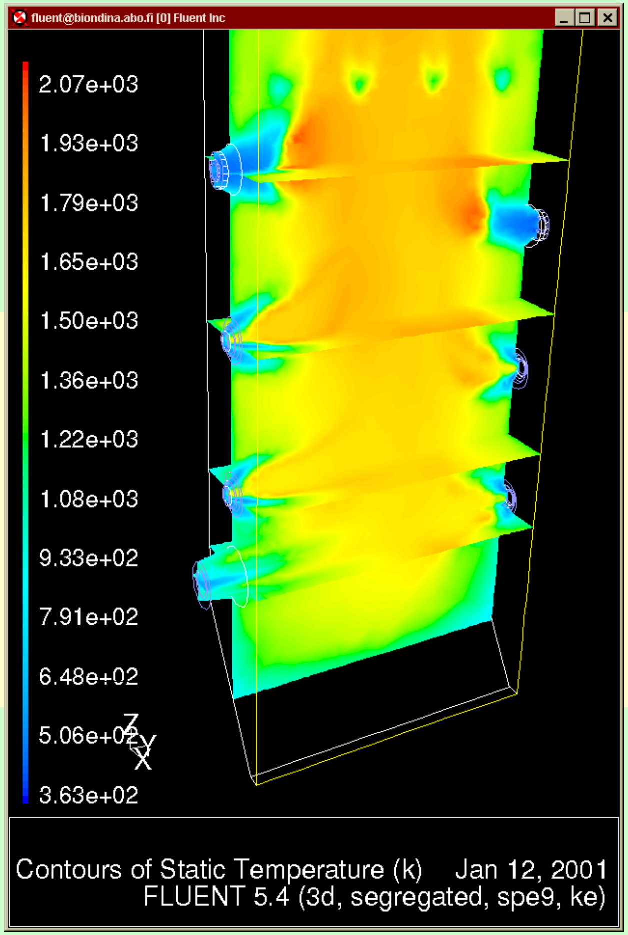
- Temperature & flow field
- Concentration profiles for main species
- Possible areas of thermal NO formation

Temperature field

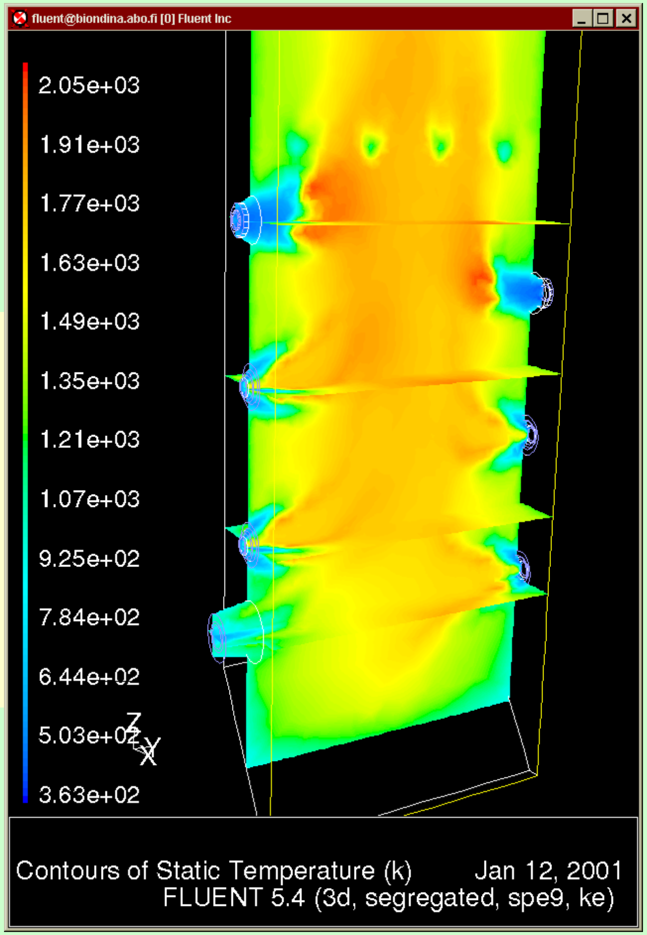
CASE I, base case



CASE II, 60 % load on L1

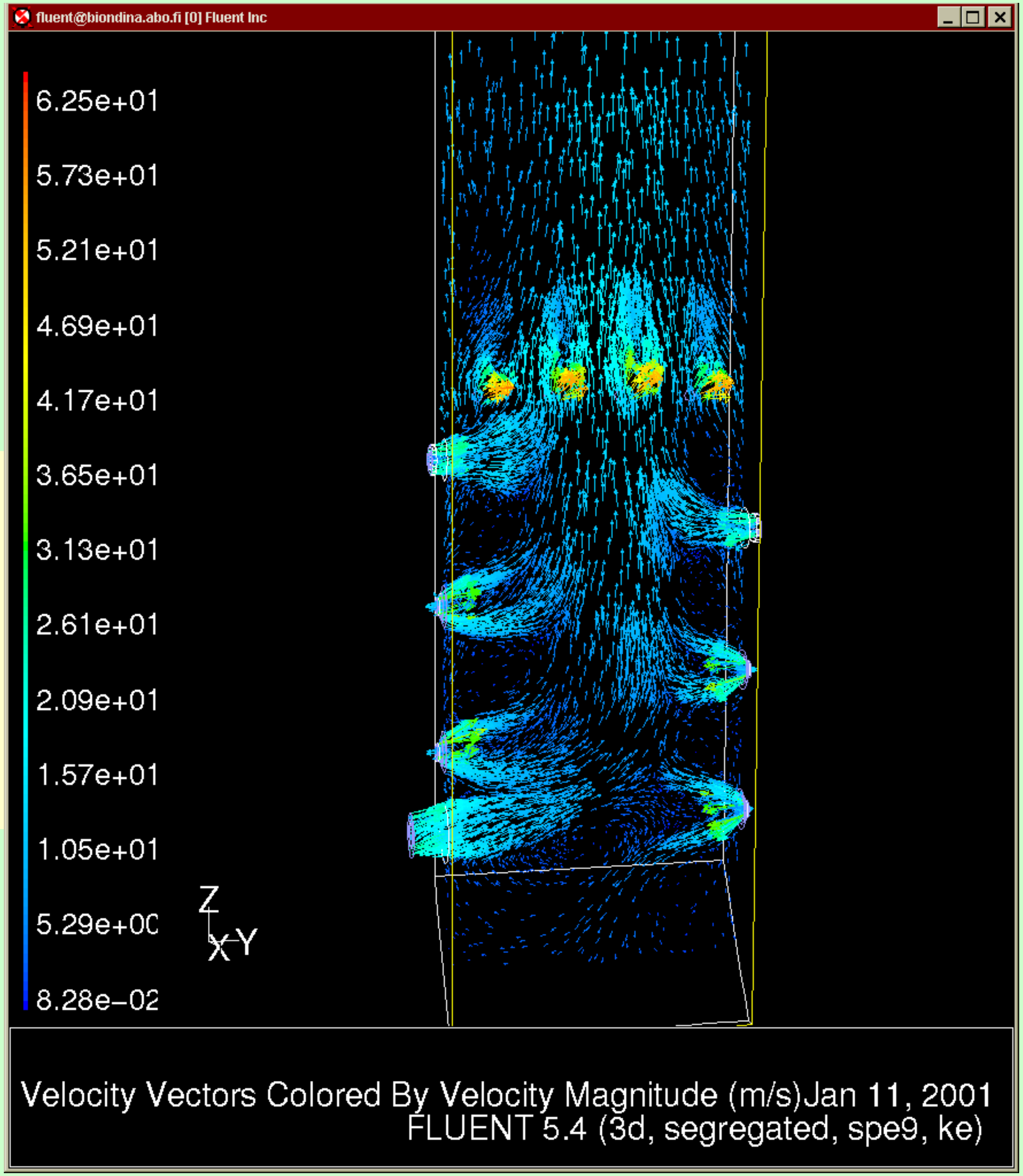


CASE III, 50 % gas



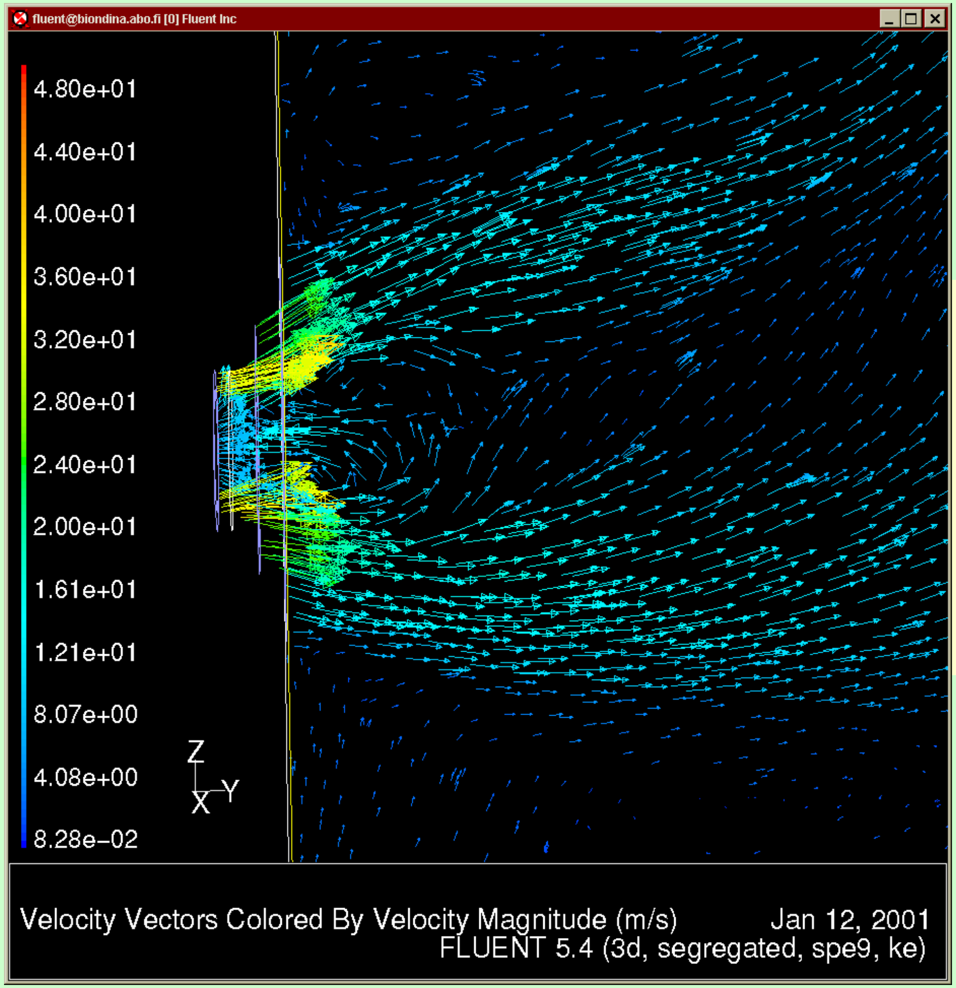
Flow field

- Strong upward gas flow in middle part of boiler, velocity 10-15 m/s
- Over-fire air penetrates well into center of boiler
- Recirculation zone under gas flame
- Recirculation zone in front of burners on level 1 and 2

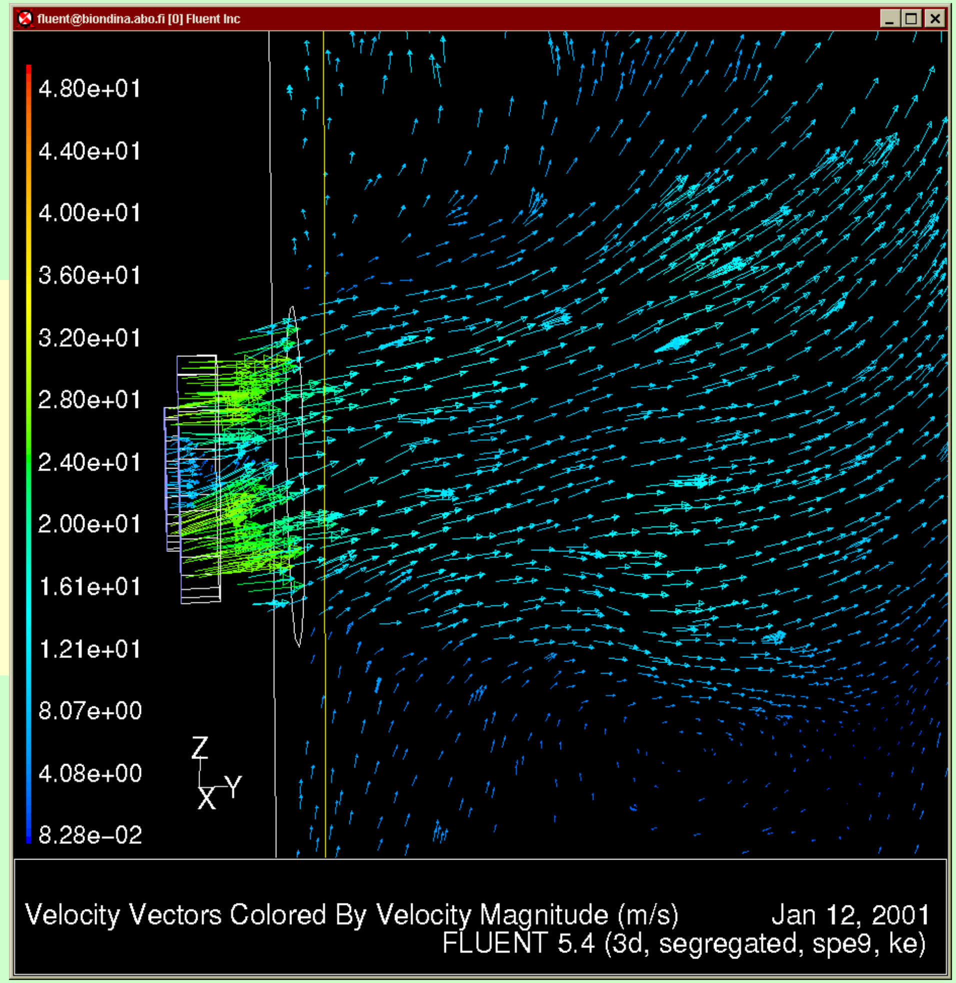


Flow field at coal burners

Low-NO_X burner on level 1

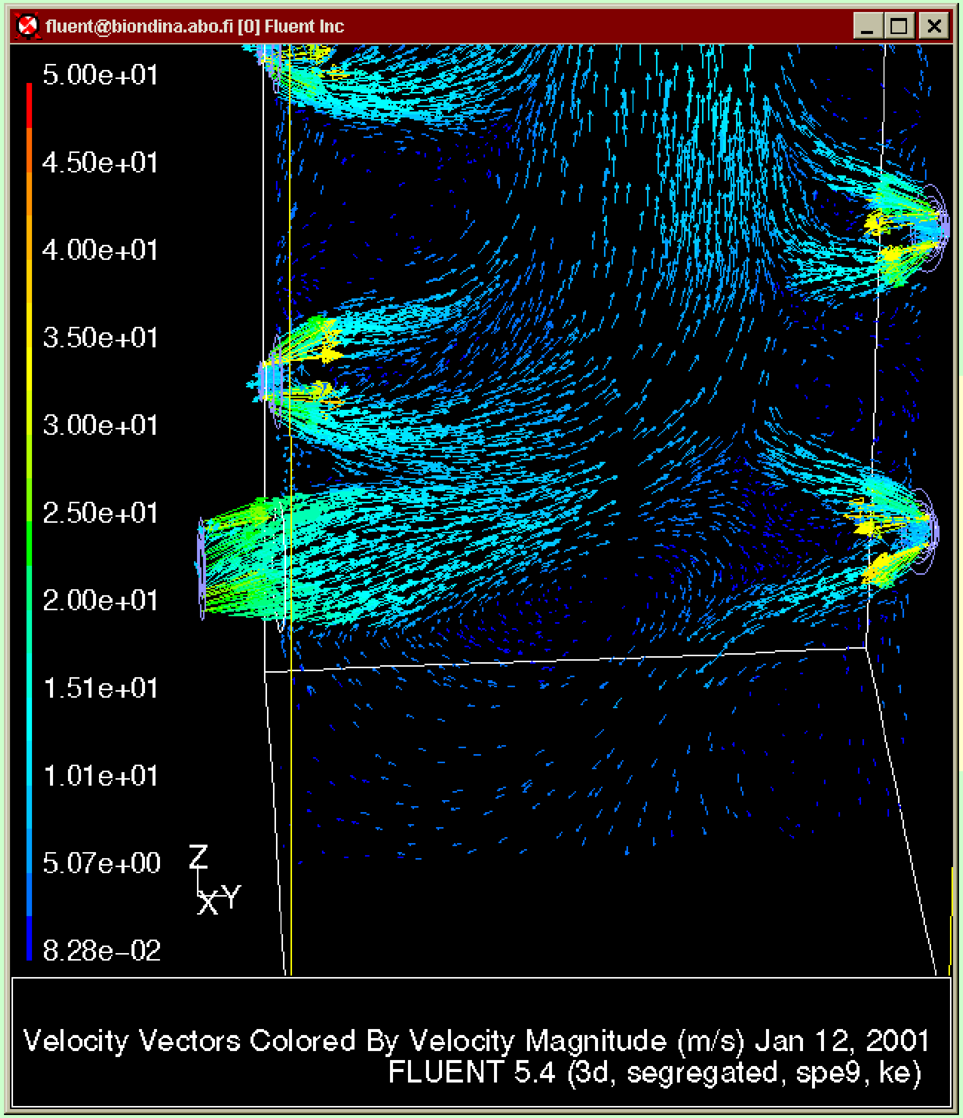


Conventional burner on level 3

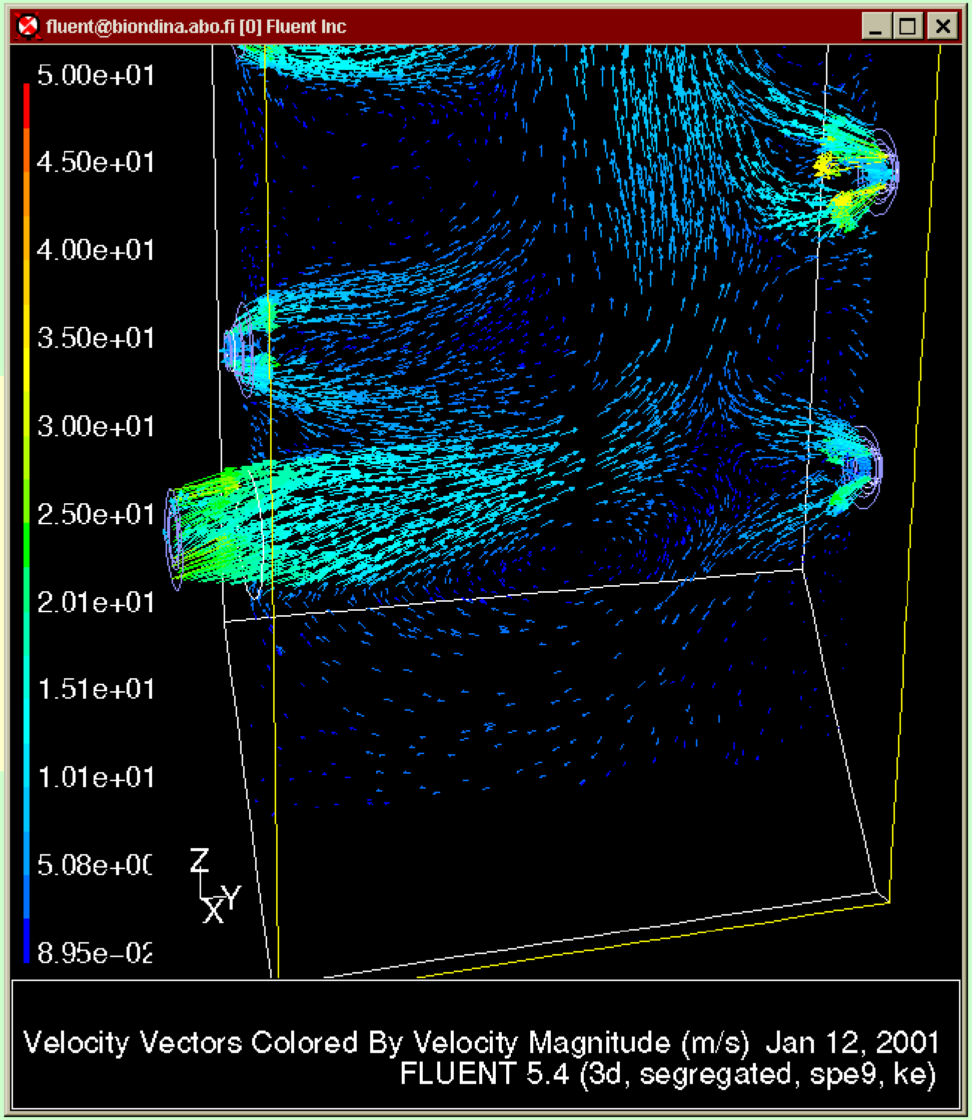


Flow field

CASE I, base case

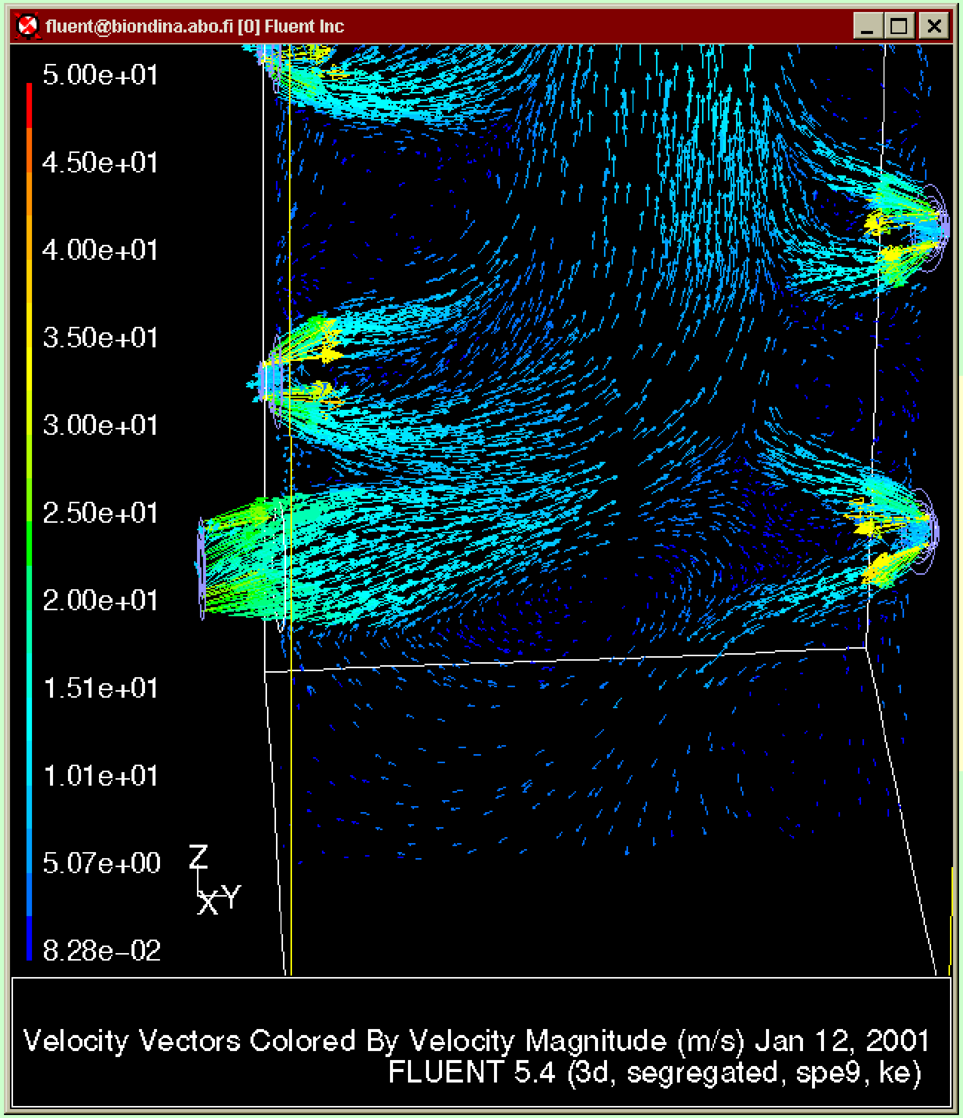


CASE II, 60 % load on L1

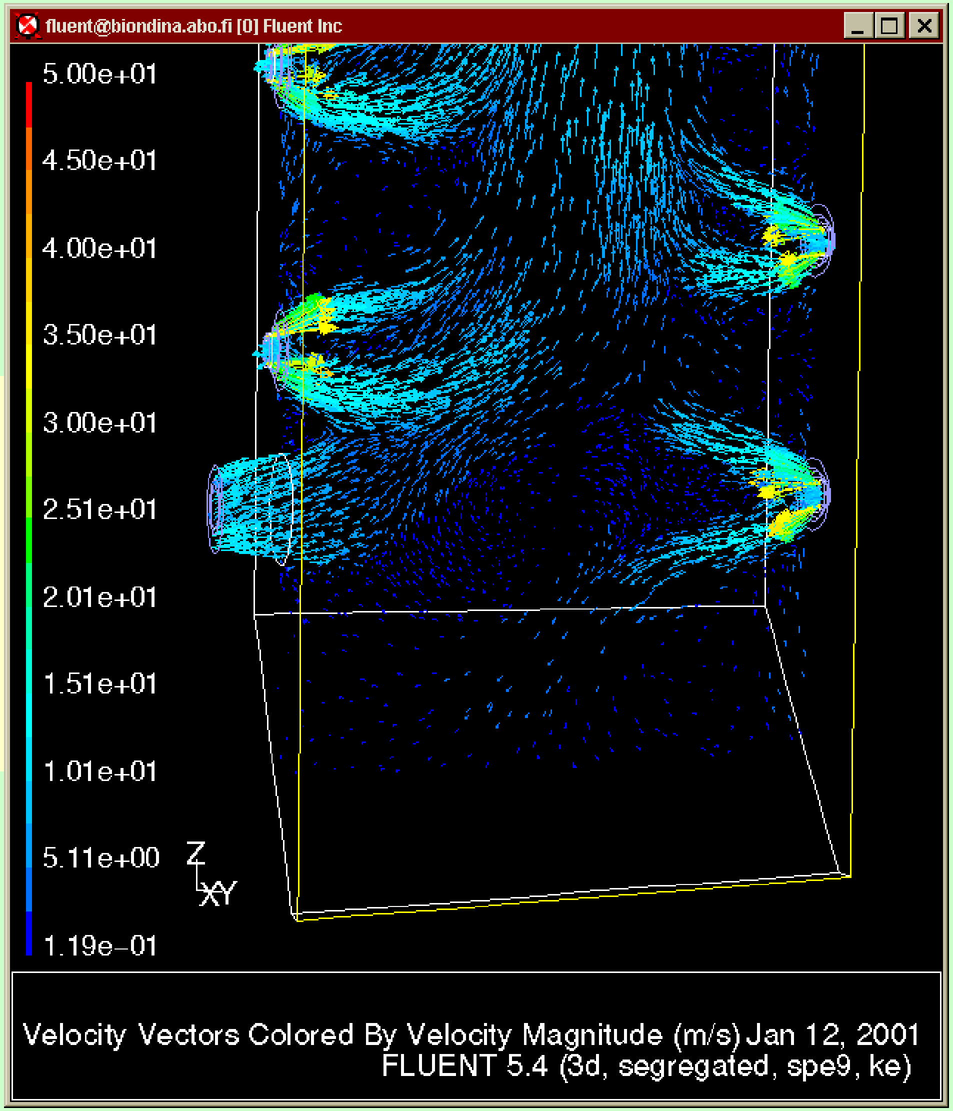


Flow field

CASE I, base case

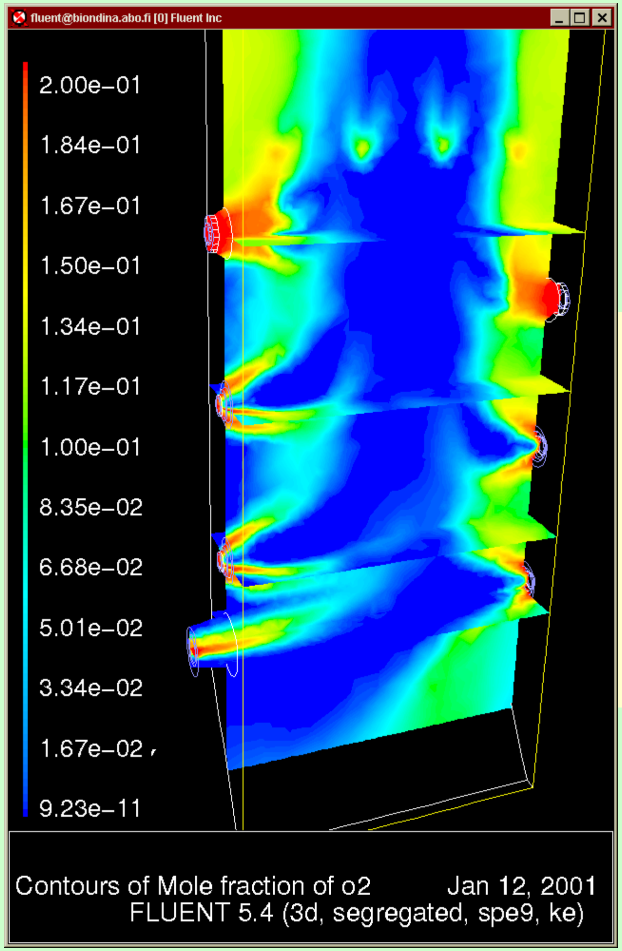


CASE III, 50 % gas

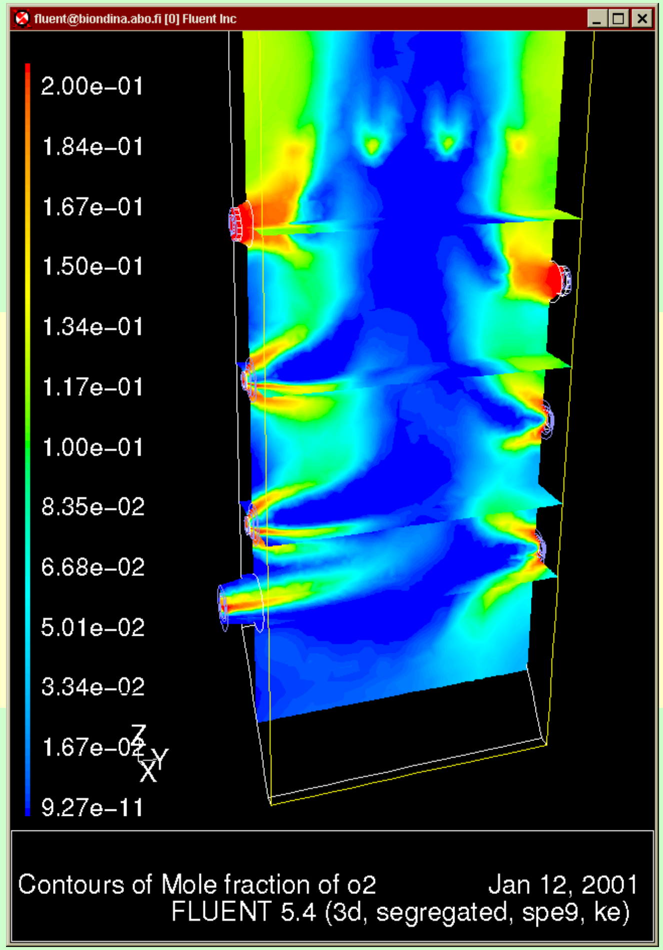


O_2 concentration

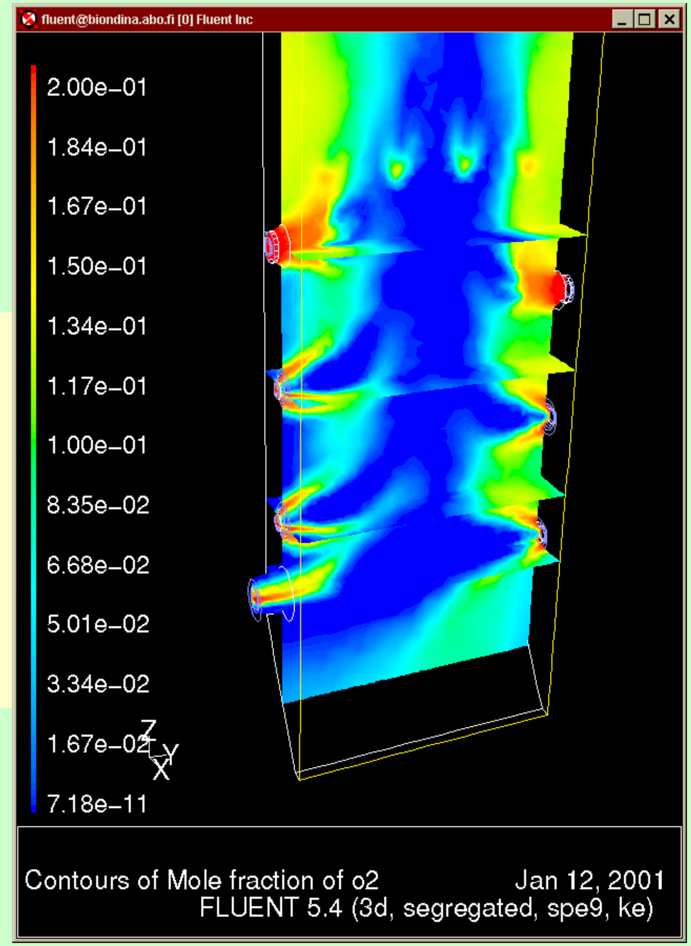
CASE I, base case



CASE II, 60 % load on L1

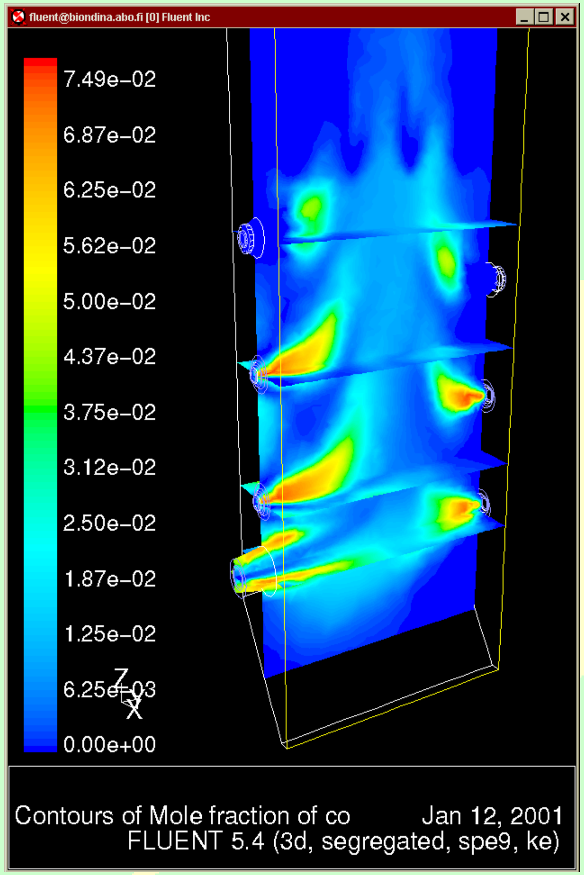


CASE III, 50 % gas

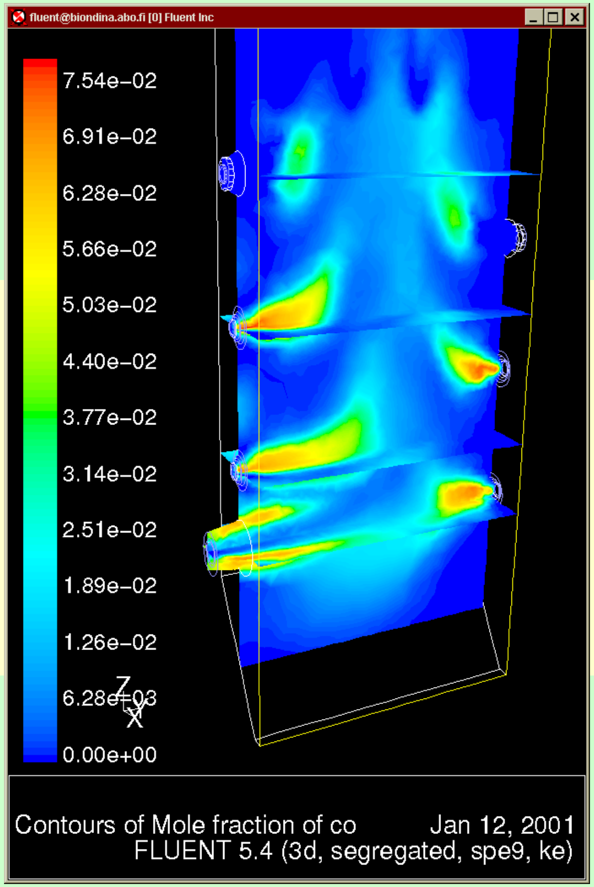


CO concentration

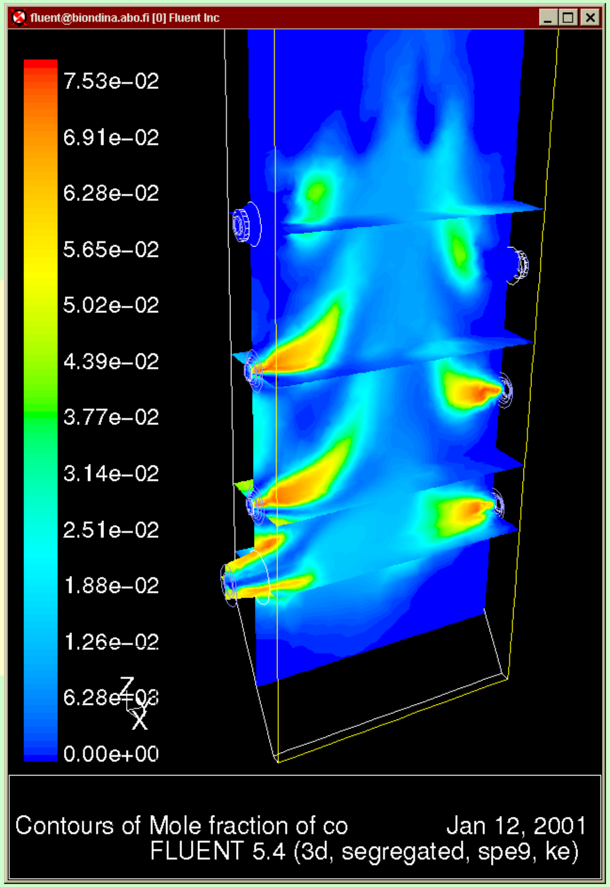
CASE I, base case



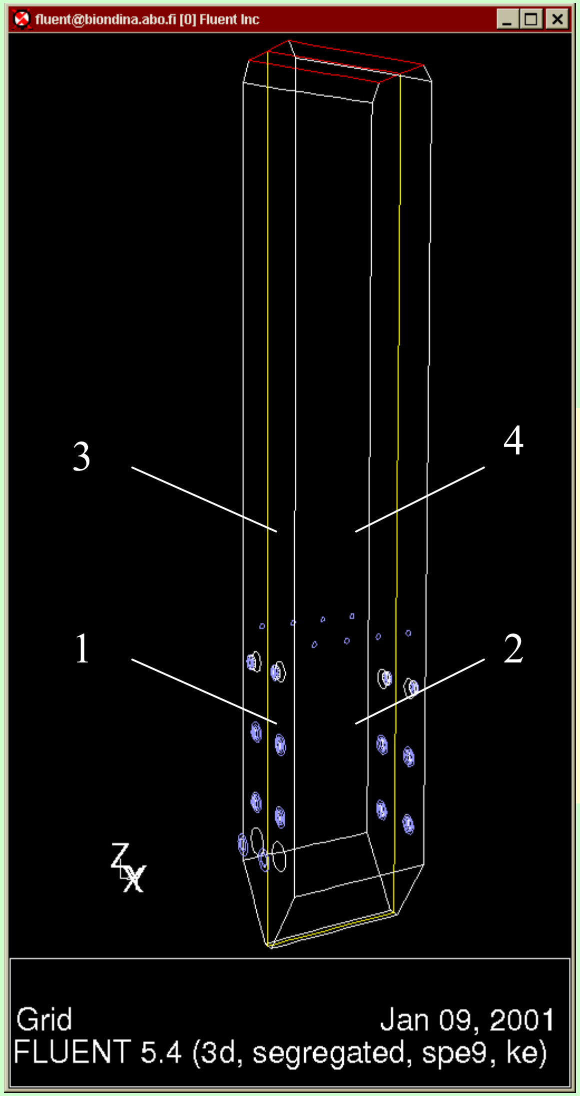
CASE II, 60 % load on L1

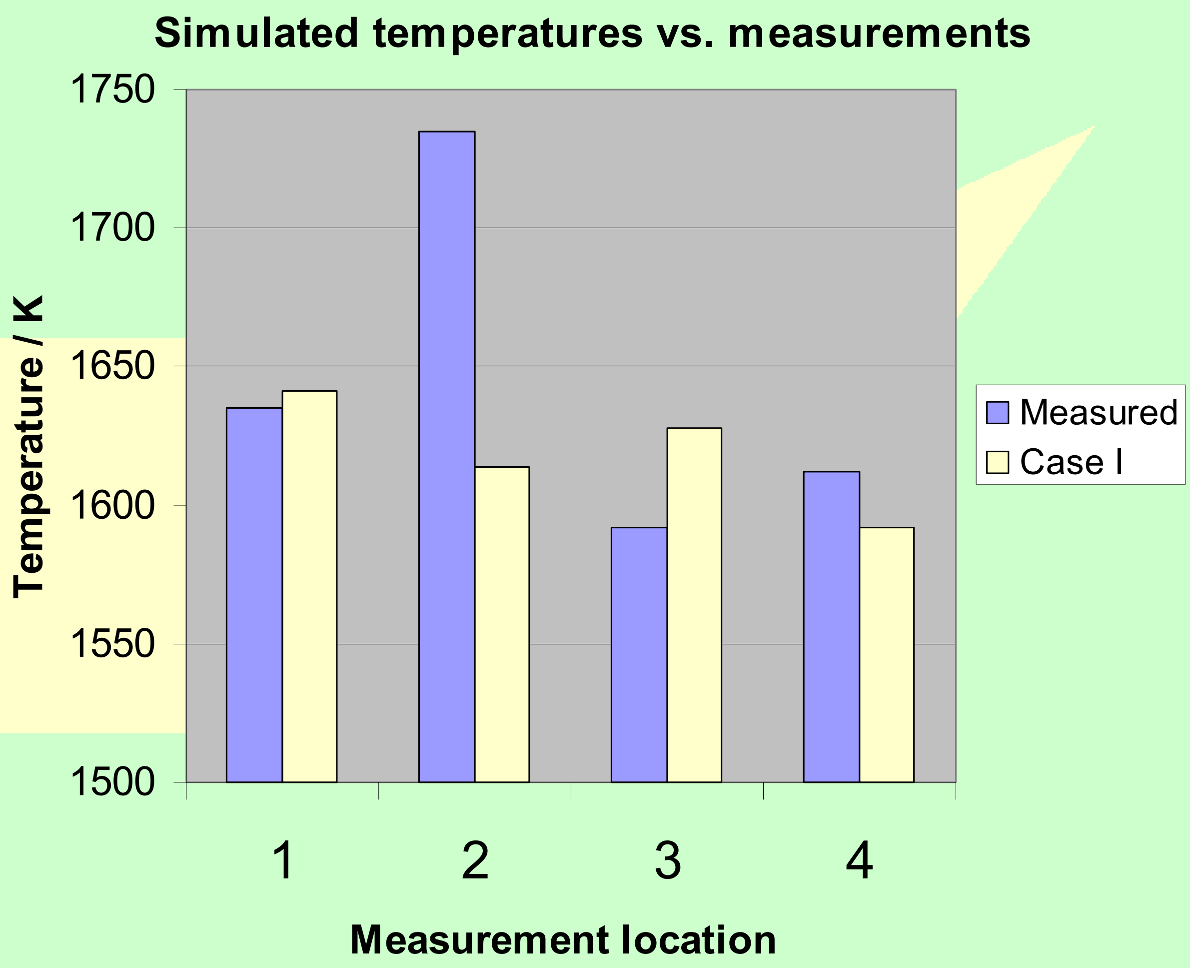


CASE III, 50 % gas



Predicted values vs. measurements





Predicted flue gas composition

vol-% (wet)	O_2	CO_2	H_2O	CO
Case I	3.1	13.8	10	0.01
Case II	3.4	13.4	9.6	0.005
Case III	3.2	13.7	8.8	0.005
Measured	*3.6-4.0*	*NaN*	*10-12*	*NaN*

Risk for formation of thermal NO?

- Conventional burners (peak temperatures > 1800 °C)
- Cooling effect of gas burners → decreased risk for formation of thermal NO on level 1
- Gas flame too cold (peak temperatures < 1400 °C)

6. Conclusions

- Temperature- flow and conc. fields well predicted
- Changing feeding strategy has mostly local effect
- Cooling effect of gas flame on level 1 temperatures
- Thermal NO likely formed @ conventional burners
- Detailed testing of available submodels for coal combustion using simpled, 2-D grid.
- Future: Implement more accurate submodels for coal combustion modelling into FLUENT® 5