A comprehensive model for large-scale CFB units

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Aim & Background

→ Comprehensive

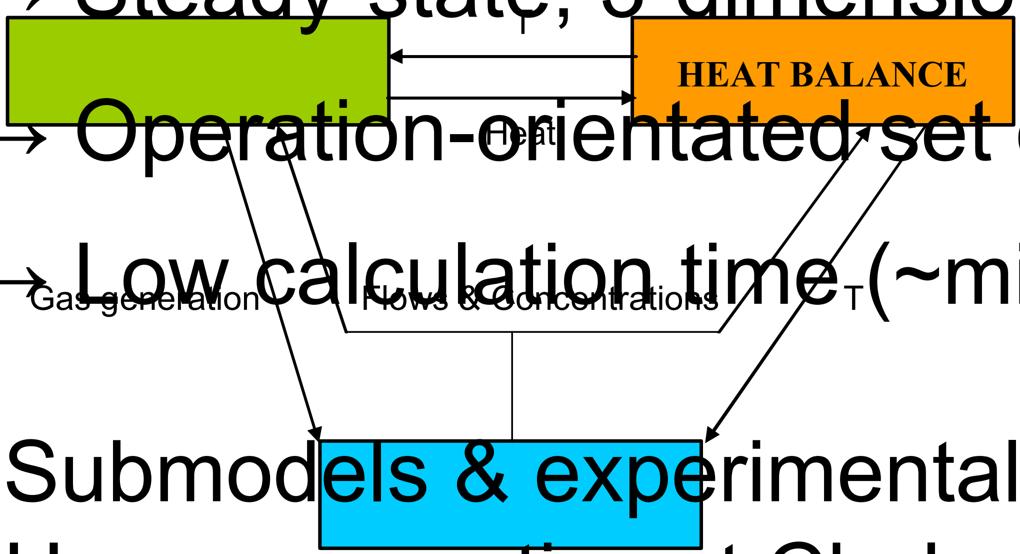
→ Universal

→ Steady-state, 3-dimensional

→ Operation-orientated set of inputs

→ Low calculation time (~min)

Phenomenology



Geometry

- Submodels & experimental data from literature
- Human expertise at Chalmers

CFB comprehensive modeling

-1996	Hannes (Preto)	1.5-D	Riser
1989-present	Werdermann, Knöbig, Lücke, Wischnewski (Werther, Hartge)	3-D	Loop
1998-2001	Joule III participants	1.5-D	Riser
2005-present	Pallarès (Johnsson)	3-D	Loop

Chalmers model development

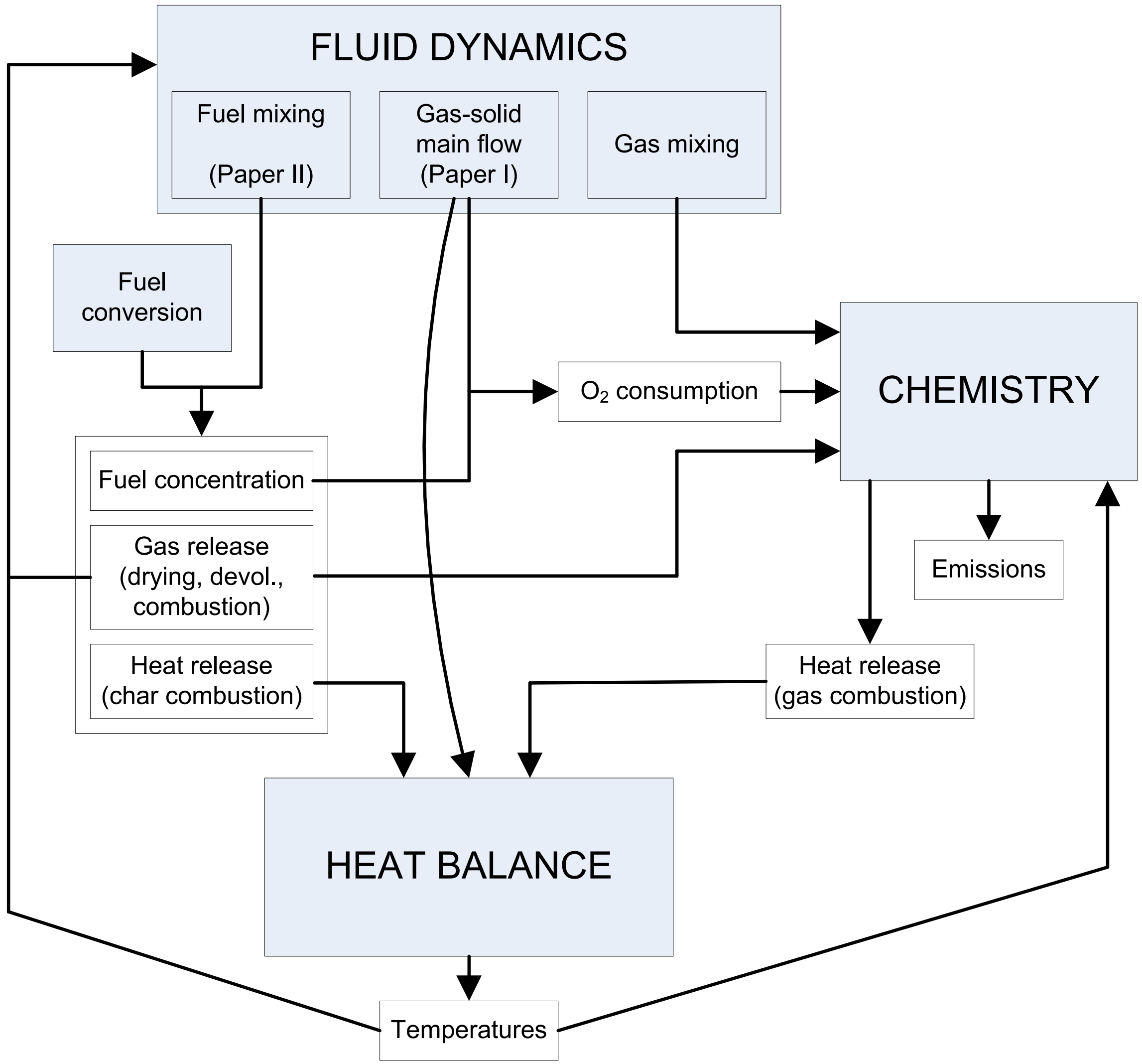
Joule III Project

1998-2001: Submodel for CFB fluiddynamics

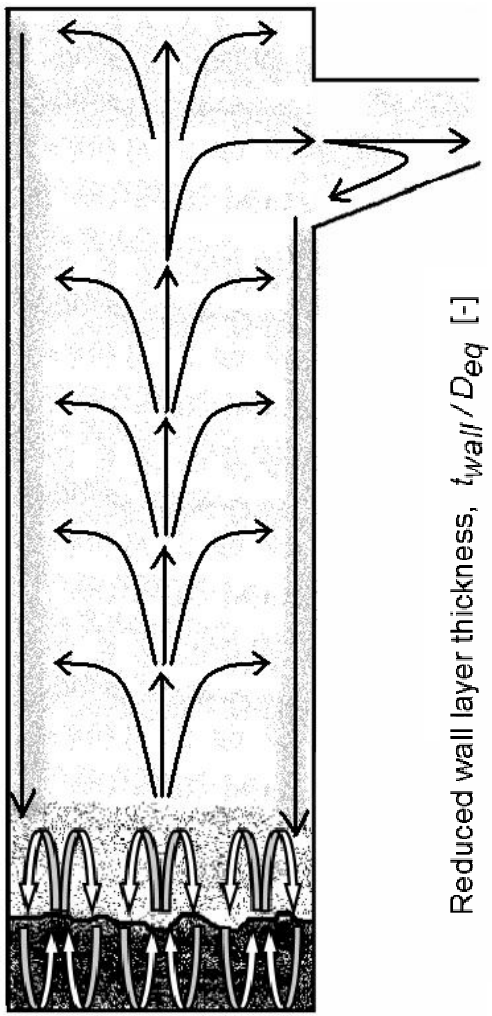
2005-2007: P1. Overall CFB model (PhD)

2008-2009: P2. Refined CFB model

Submodels coupling



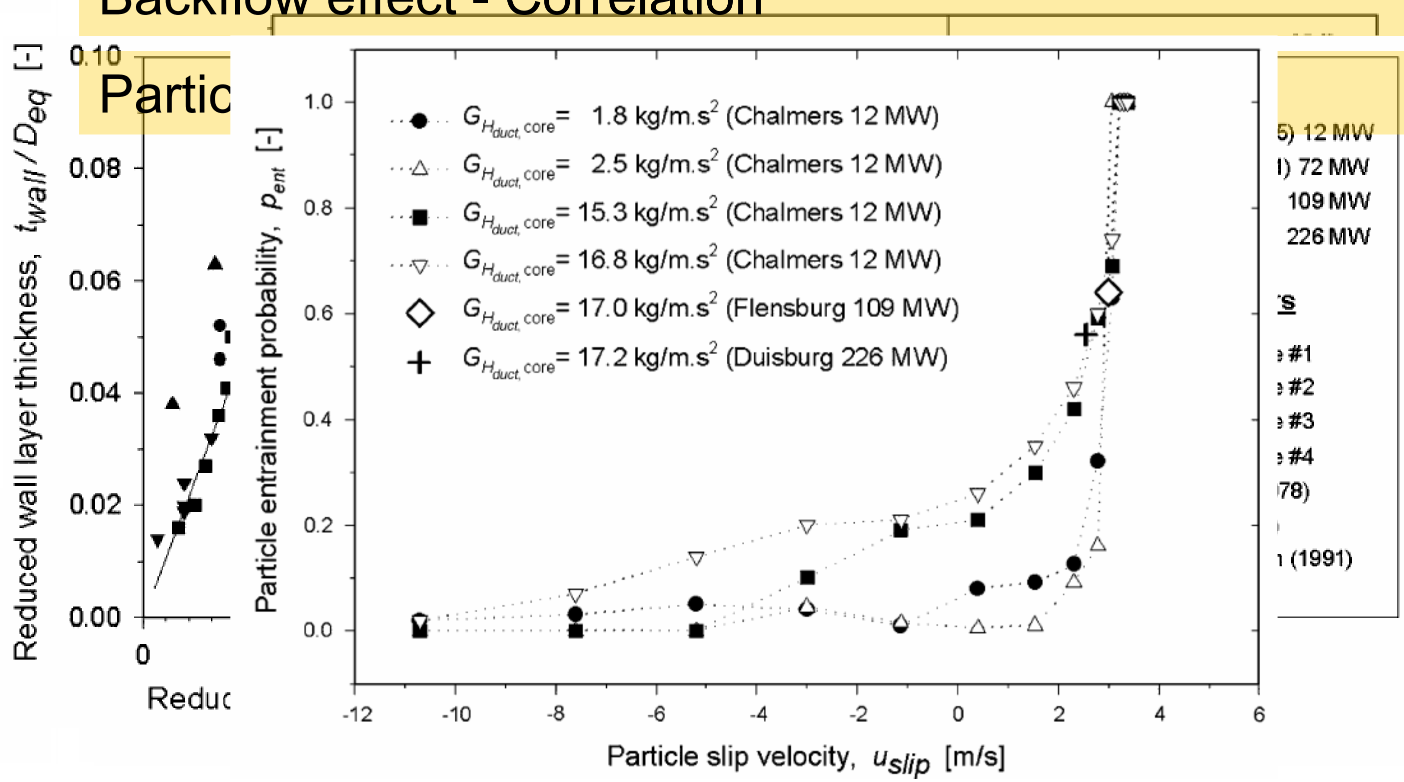
Inert solids fluiddynamics



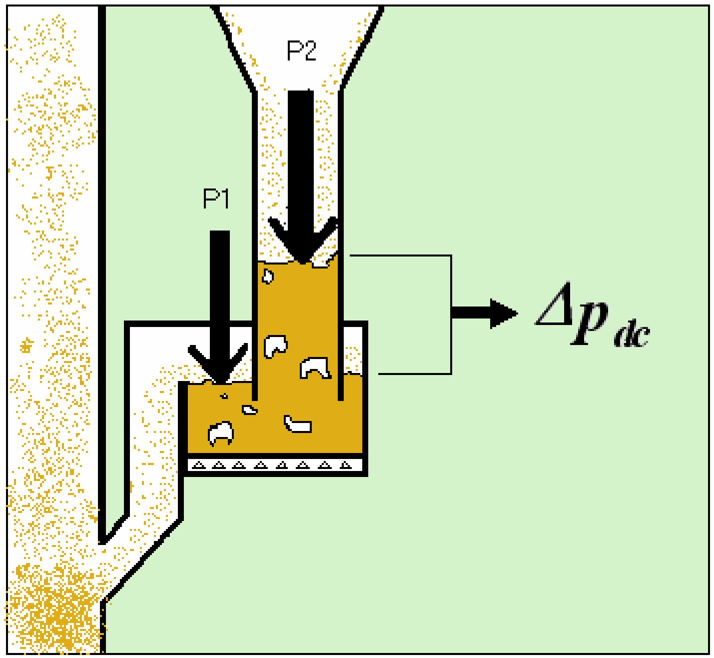
- Cluster & disperse phases (Johnsson and Leckner)
- Wall layer thickness – Correlation
- Backflow effect - Correlation
- Partic

Chalmers 12 MW$_{th}$ CFBC

u_0 = 2.7 m/s , d_s = 320 μm



Inert solids fluiddynamics



Pressure balance on circulating loop

↓

Δp_{dc}

↓

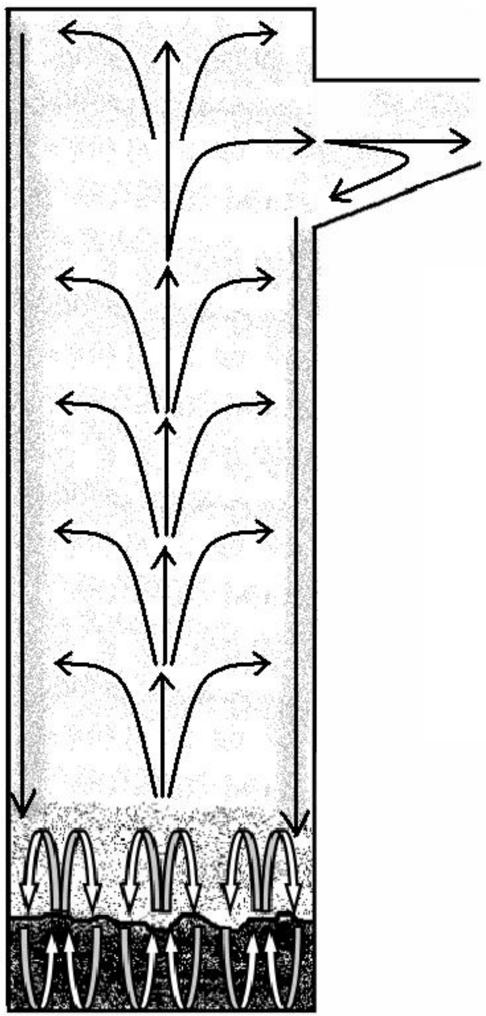
m_{dc}

↓

Population balance on circulating loop

Pallarès, D., Johnsson, F.
"Macroscopic modeling of fluid dynamics in large-scale circulating fluidized beds"
Progress in Energy and Combustion Science 32 (2006)

Fuel mixing & conversion



- Varying particle size & density

  Dynamical simulation of the mixing of a fuel batch during all its burnout time is required.

  Continuous fuel feeding is later approximated by superposition of time-delayed fuel batches.

- Strong horizontal gradients

  Horizontal fuel dispersion is approximated macroscopically by Brownian diffusion process (D_h~0.1 m^2/s).

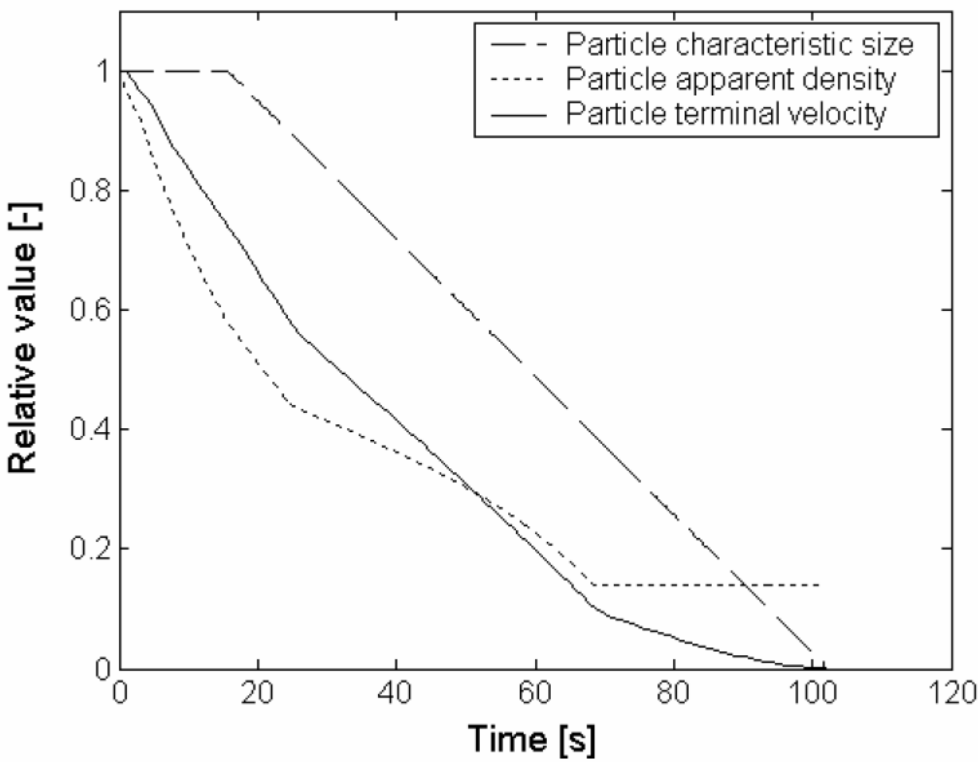
Fuel mixing & conversion

Palchonok *et al.*

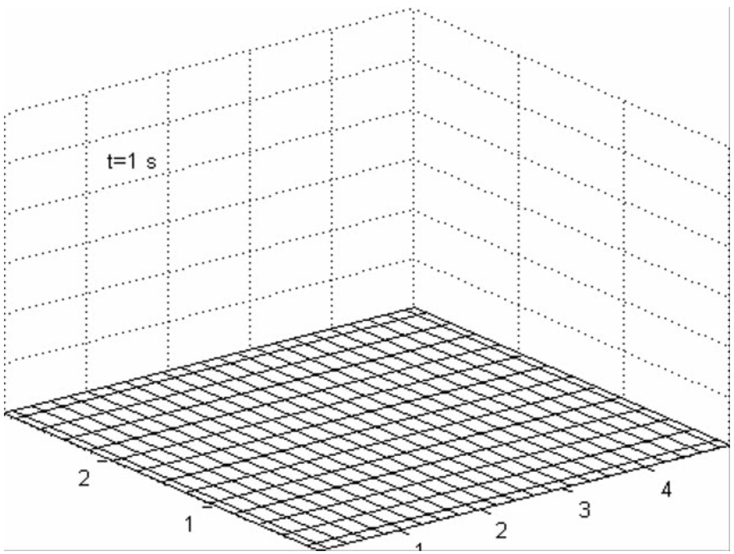
- Fuel particle approximated as ∞-plane, ∞-cylinder or sphere
- Quasi-steady state

$$\frac{1}{r^n}\frac{\partial}{\partial r}\left(r^n k_c \frac{\partial T}{\partial r}\right) - \frac{1}{r^n}\frac{\partial}{\partial r}\left(r^n u_g \rho_g c_{pg} T\right) = 0$$

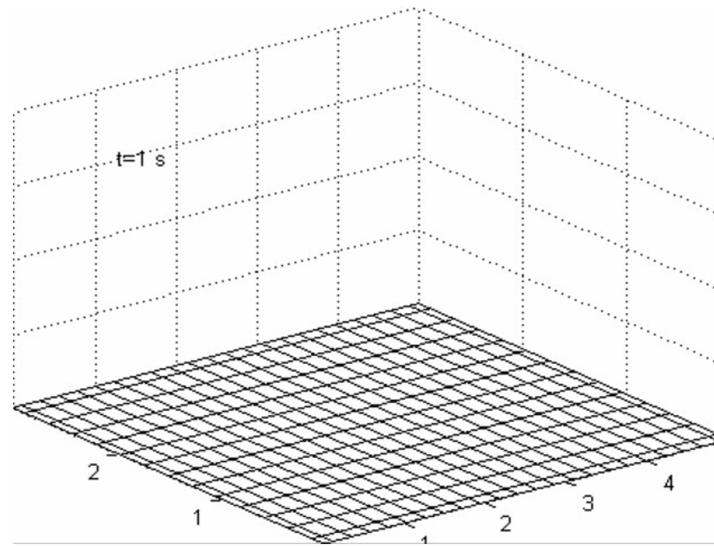
(analytical solution)



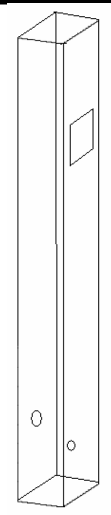
Fuel mixing & conversion



Fuel batch



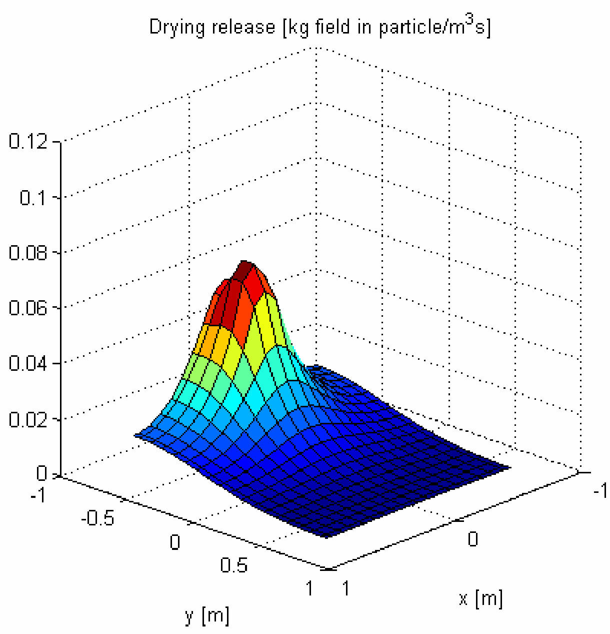
Superposition of time-delayed fuel batches

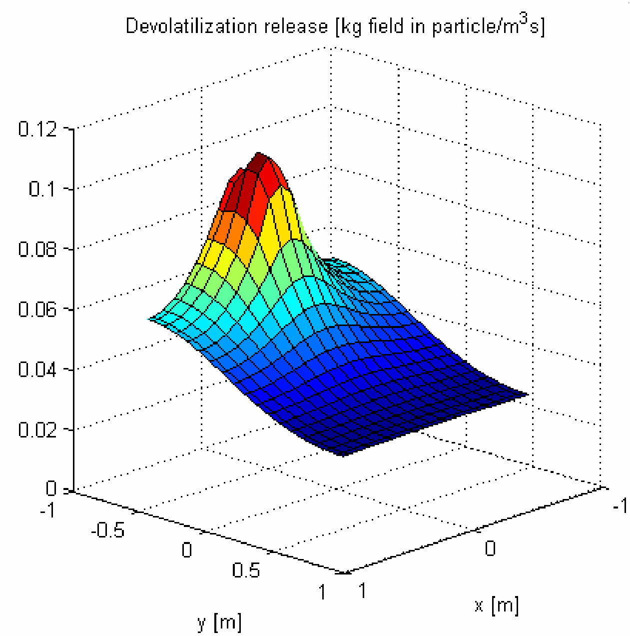


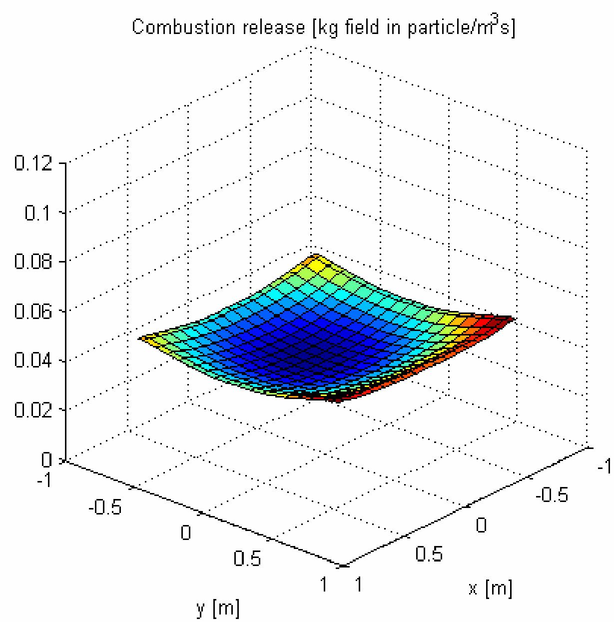
Fuel mixing & conversion

Distribution of gas releases in bottom bed

Moisture | Volatiles | CO_2

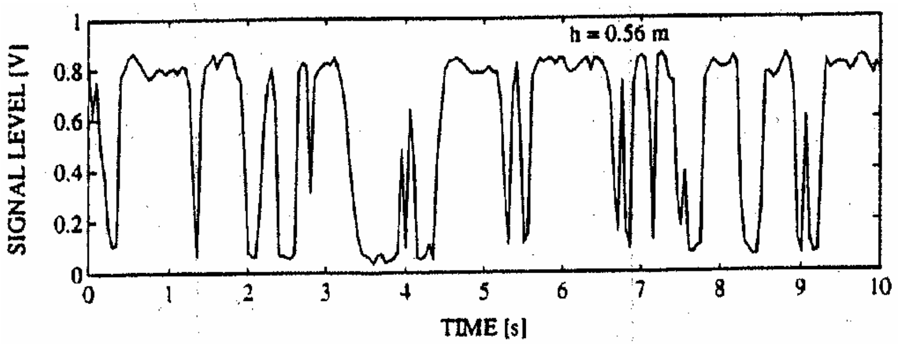




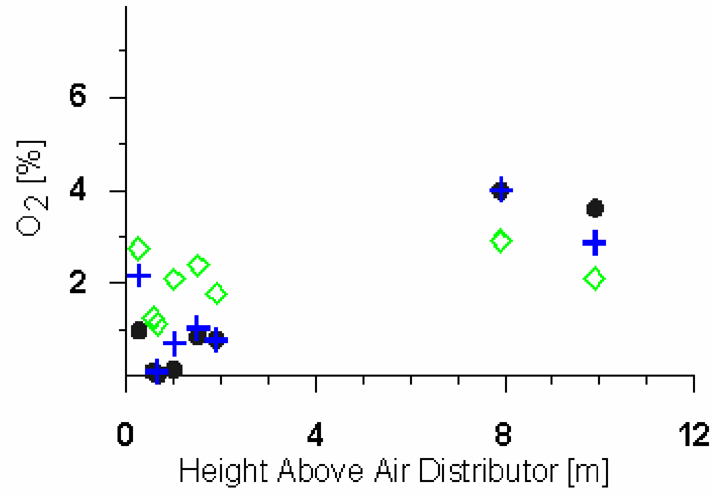


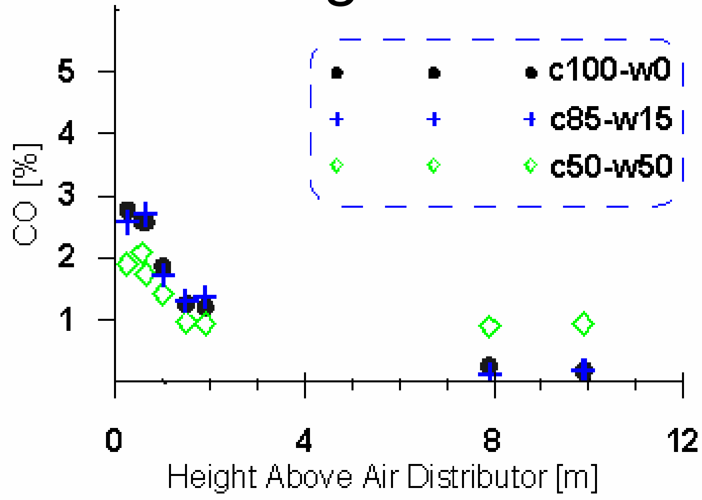
Gas mixing & combustion

Combustion kinetics are fast at typical furnace temperatures.
No coexistance of reactants.



Reactants coexist however on a time-averaged basis.





Gas mixing & combustion

Macroscopic models in literature aim at modeling the time-averaged value

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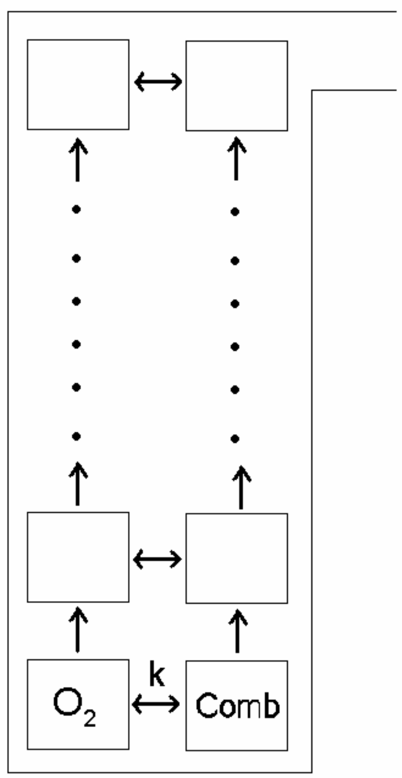
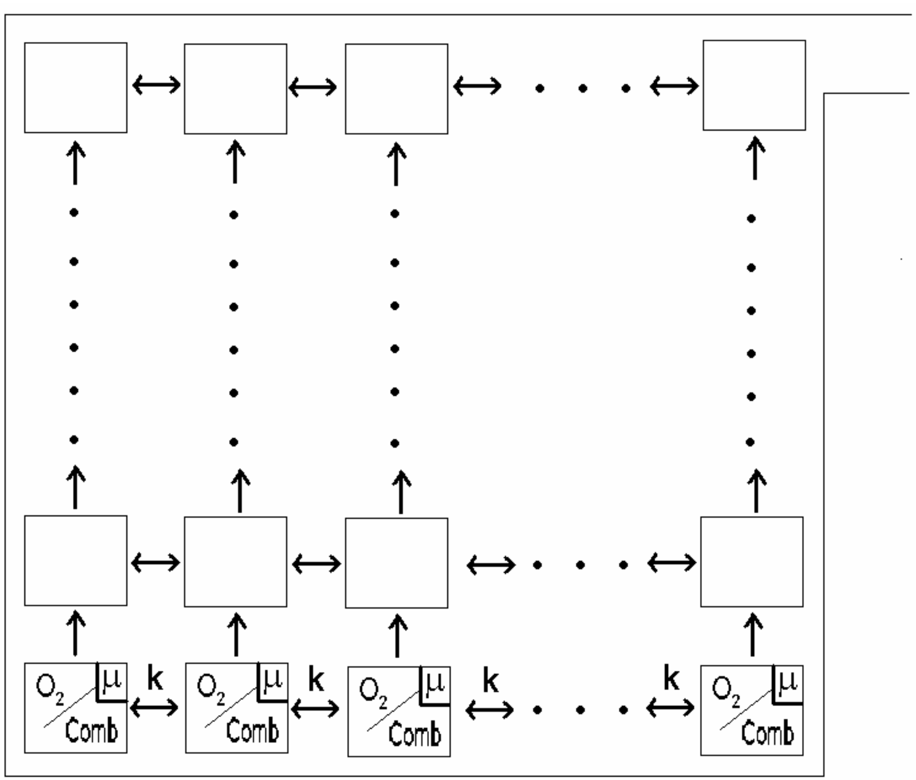
With fast combustion kinetics, a virtual mixing scale has to be used to avoid burnout and allow coexistance of reactants

1D

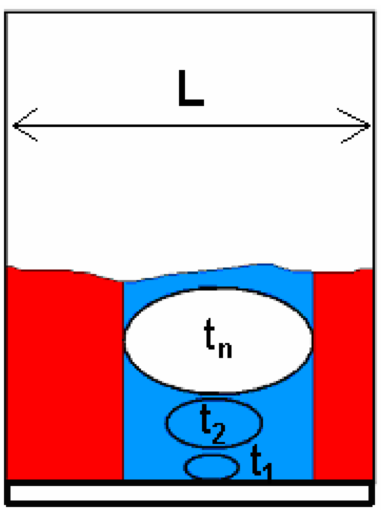


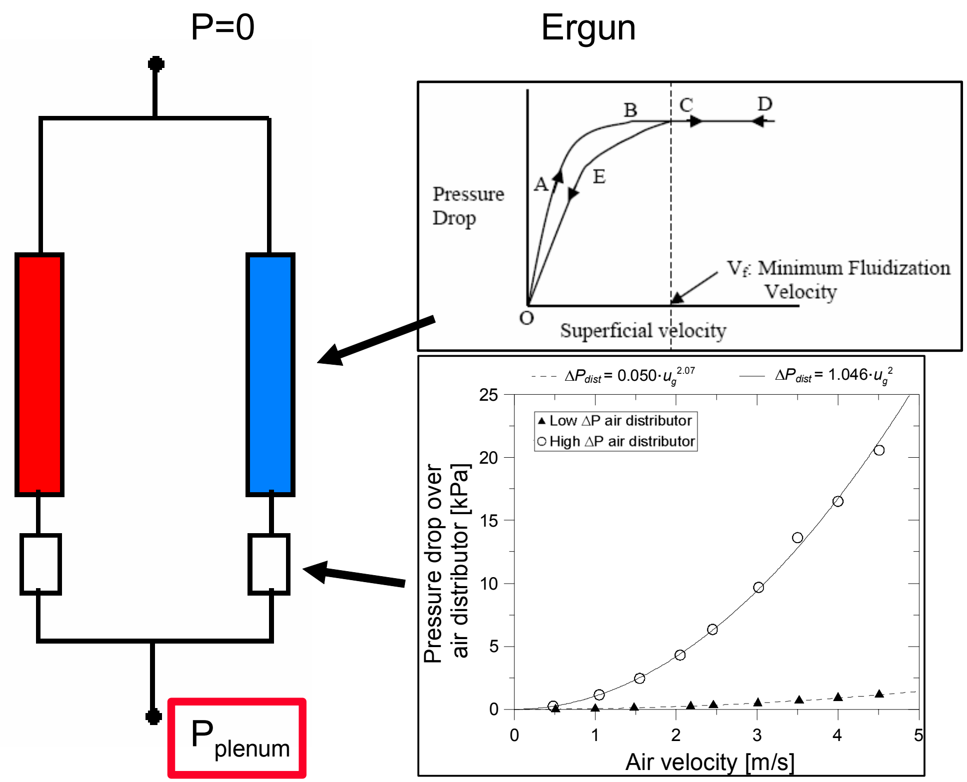
2D



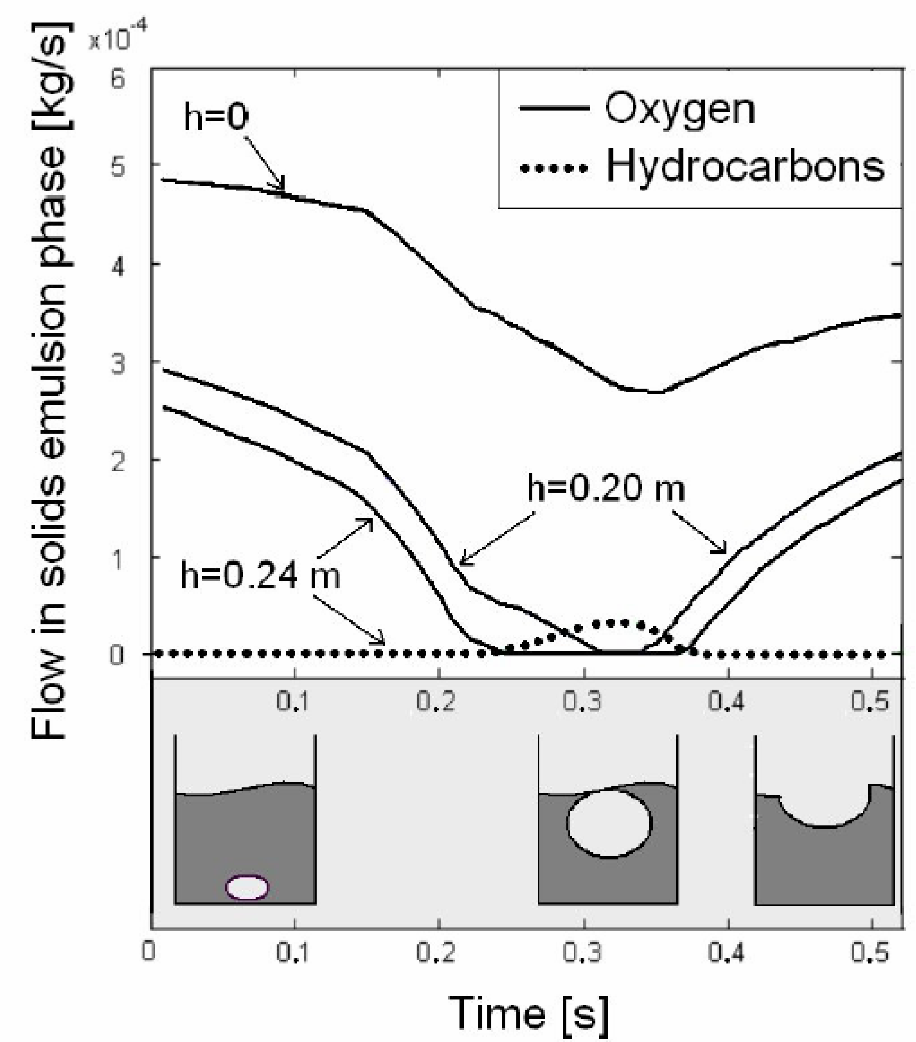
Gas mixing & combustion

Dynamical pressure balance on the gas phase



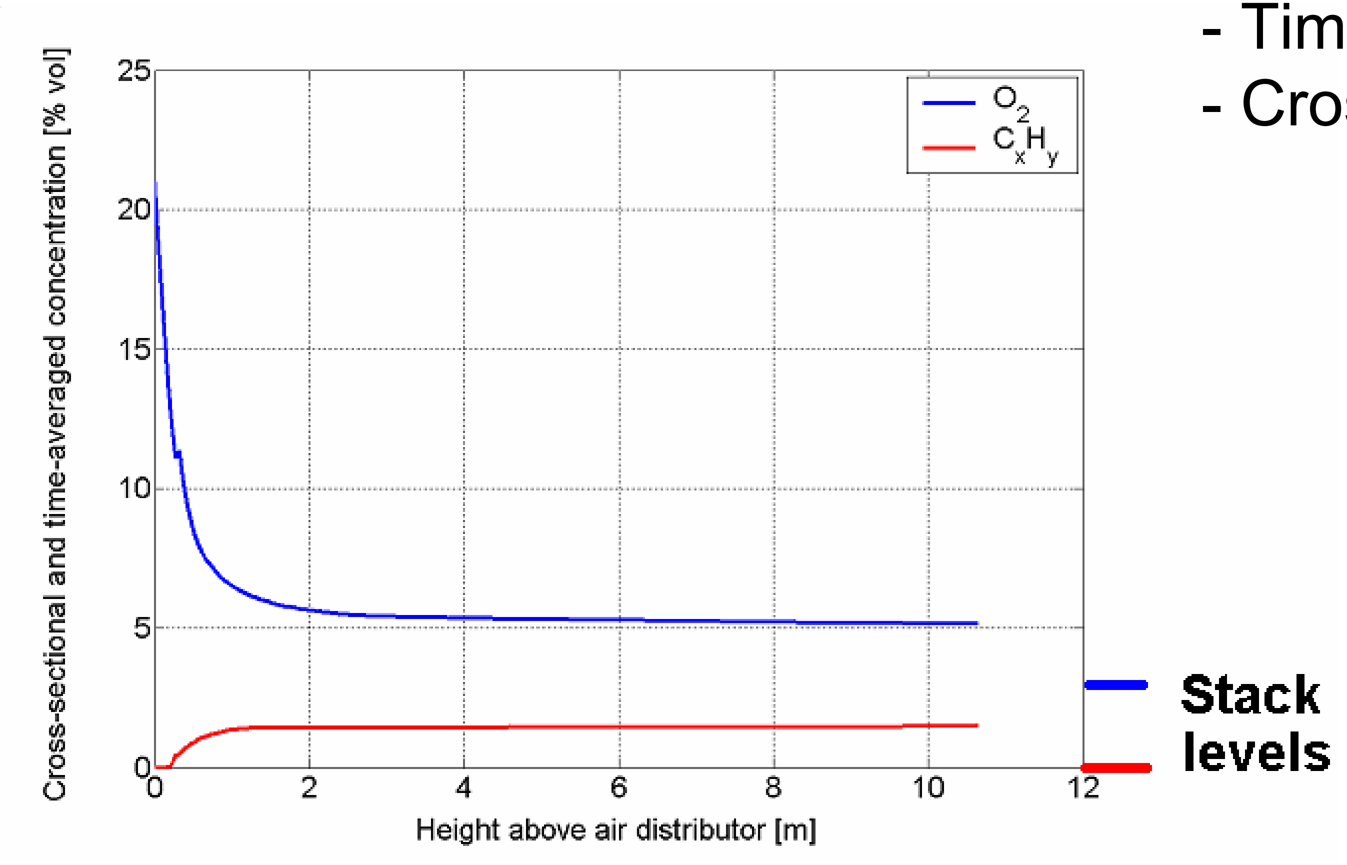


Gas mixing & combustion

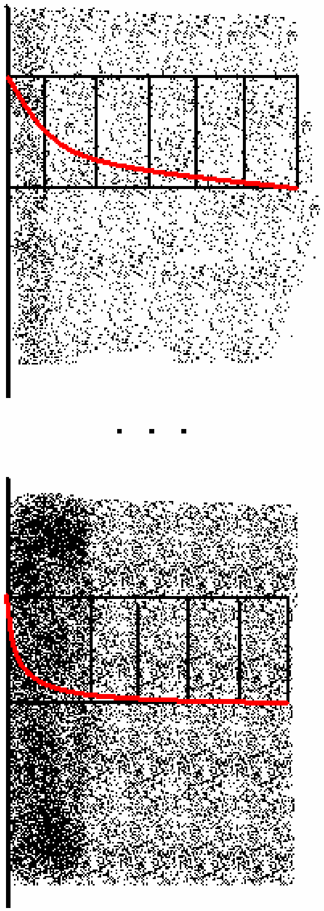


Gas mixing & combustion

Simulated data averaged in: - Gas phase
- Time
- Cross section



Heat balance - Radiation



Optical shadowing factor of a solids suspension:

$$\alpha = 1 - \exp\left(-\frac{1.5 \cdot c_v \cdot l}{d_s}\right)$$

Radiation effective T weighting for each cell:

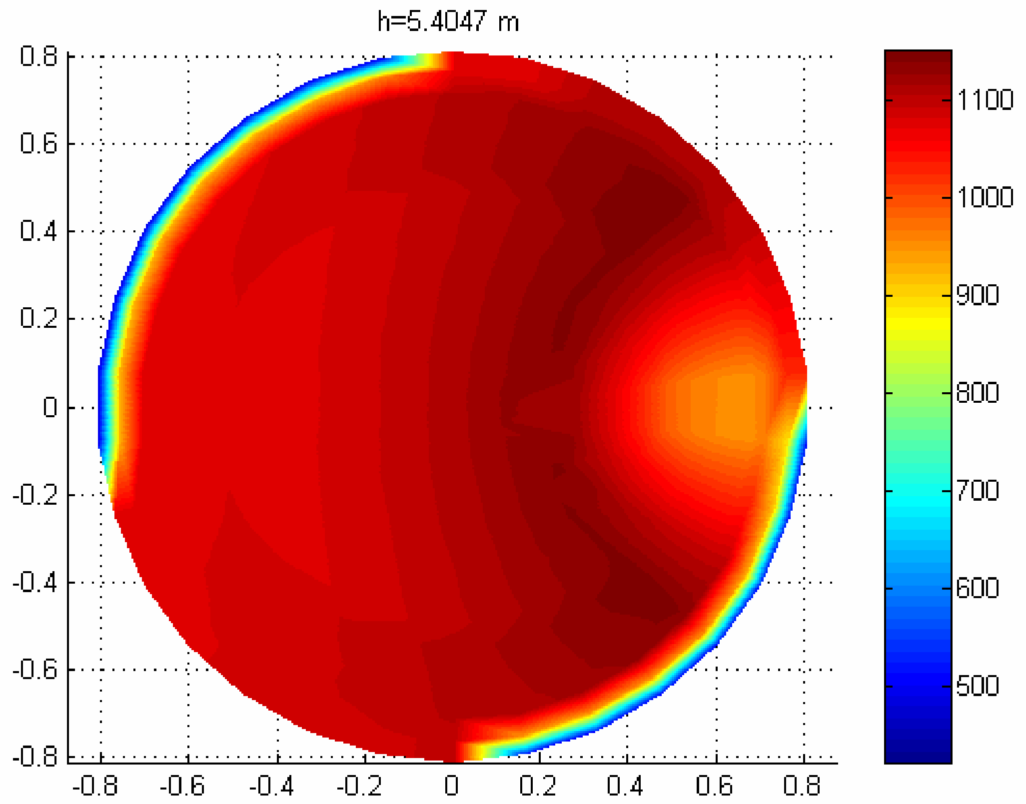
$$w_i = \alpha_i \cdot \prod_{n=1}^{n=i-1} (1 - \alpha_n)$$ → T_{eff}, , C_{eff}

→ $Q = h_{rad} A (T_{eff} - T_{wall})$

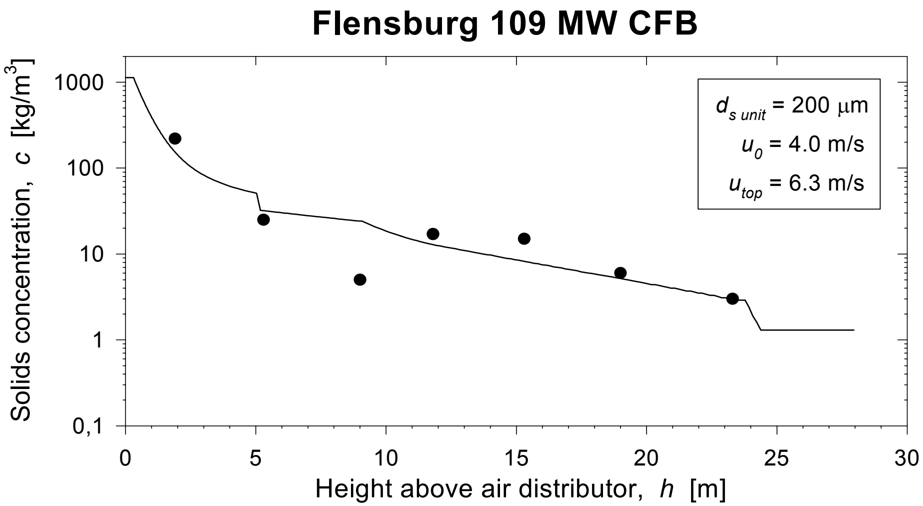
Radiation heat weighting for each cell:

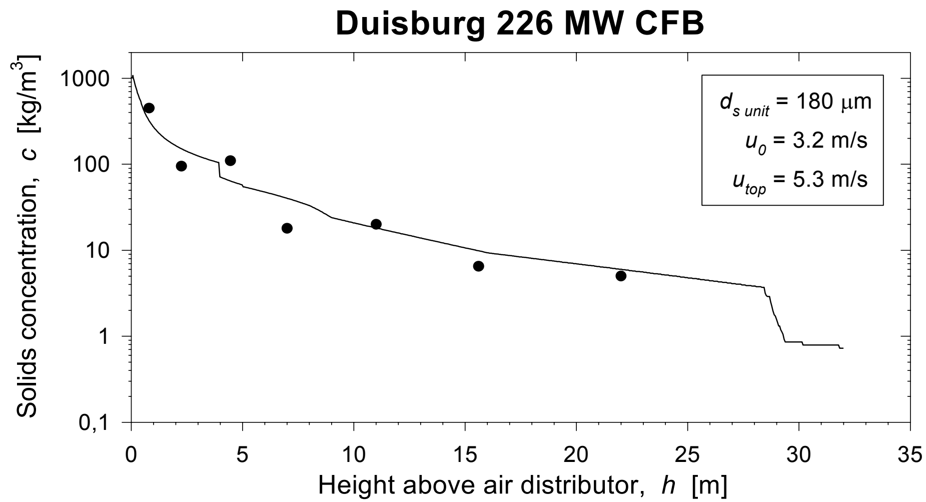
$$r_i = \frac{w_i \cdot \left(T_i^4 - T_{wall}^4\right)}{\sum_{i=1}^{N} w_i \cdot \left(T_i^4 - T_{wall}^4\right)}$$ → $Q_i = r_i Q$

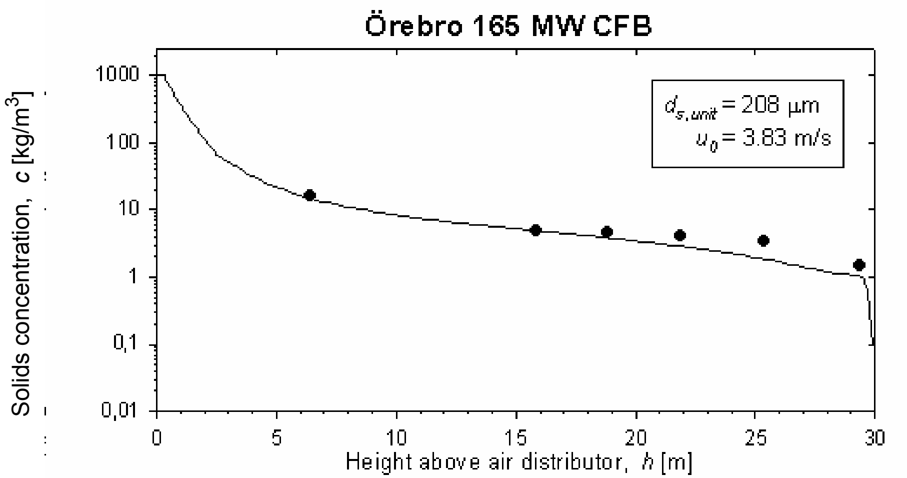
Temperature field



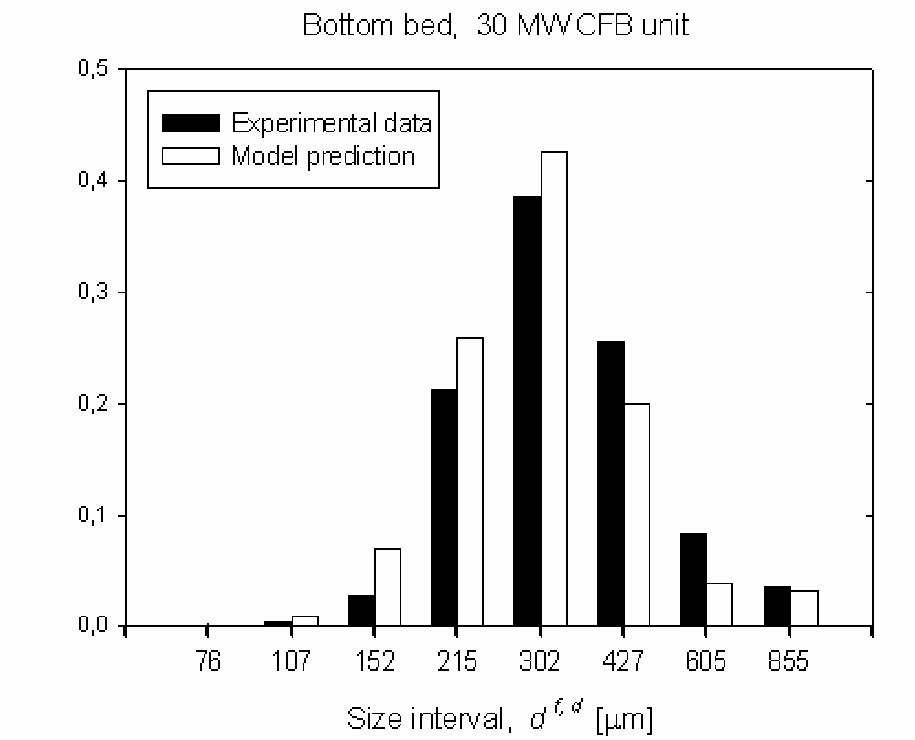
Solids concentration profiles

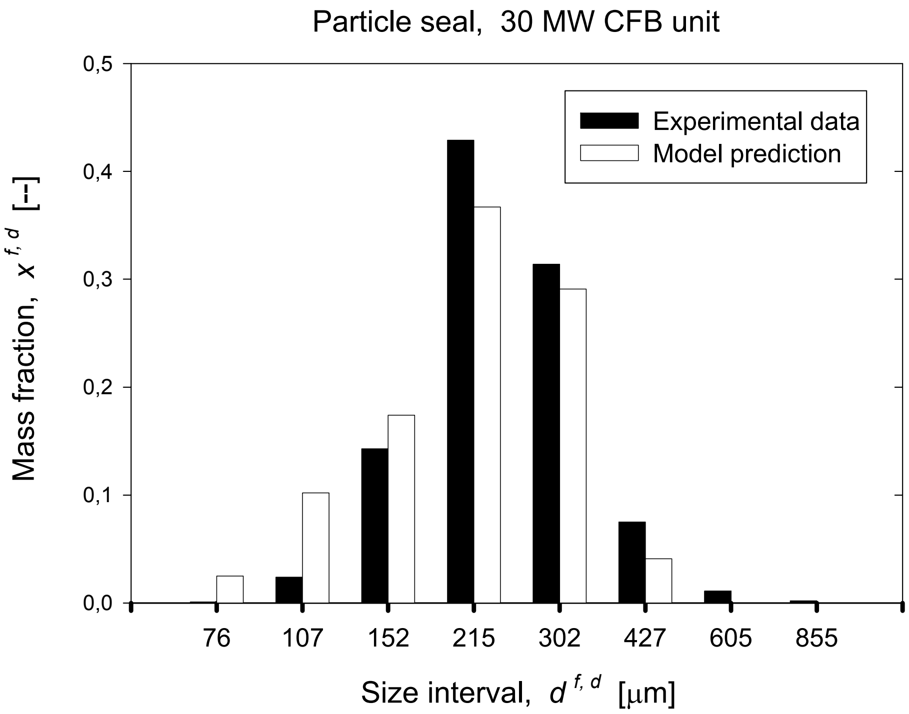






PSD distribution in CFB loop

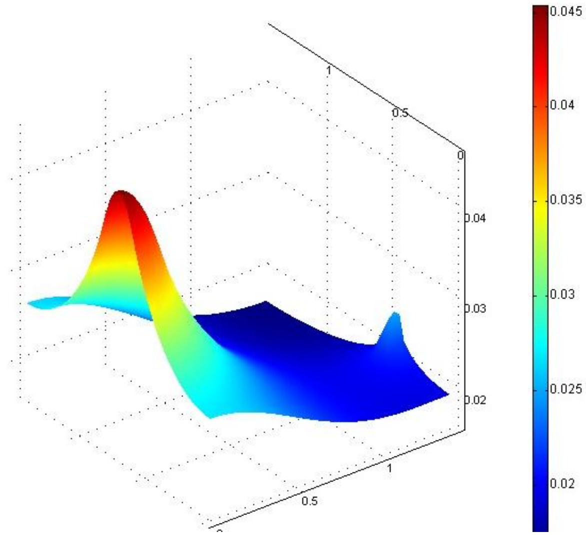


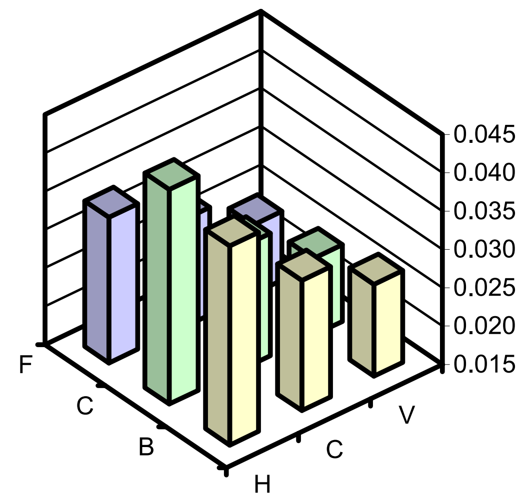


Fuel concentration in dense bed

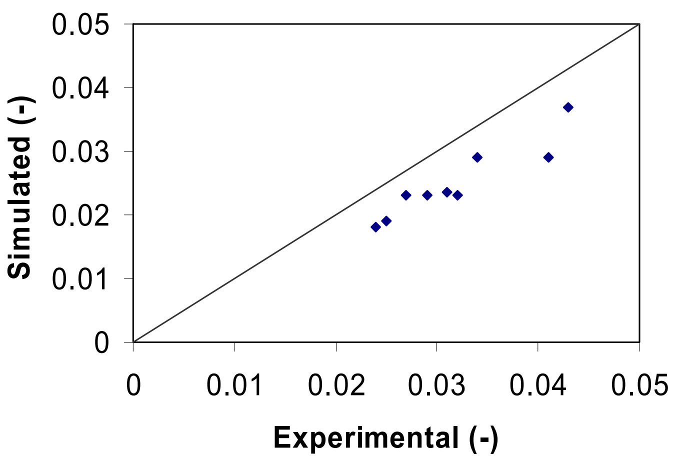
u_0 = 3.81 m/s
m_{fuel} = 0.303 kg/s
P = 9.43 MW

Volatiles (wt% daf)	40.2
Proximate analysis (wt% a.r.)	
Combustibles	74.2
Ash	8.9
Moisture	16.9
Ultimate analysis (wt% daf)	
C	78.4
H	5.5
O	12.7
S	1.84
N	1.60
Heating value (MJ/kg low, daf)	31.09





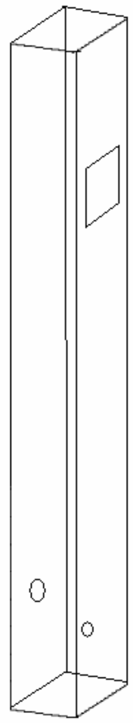
Char fraction in bottom region

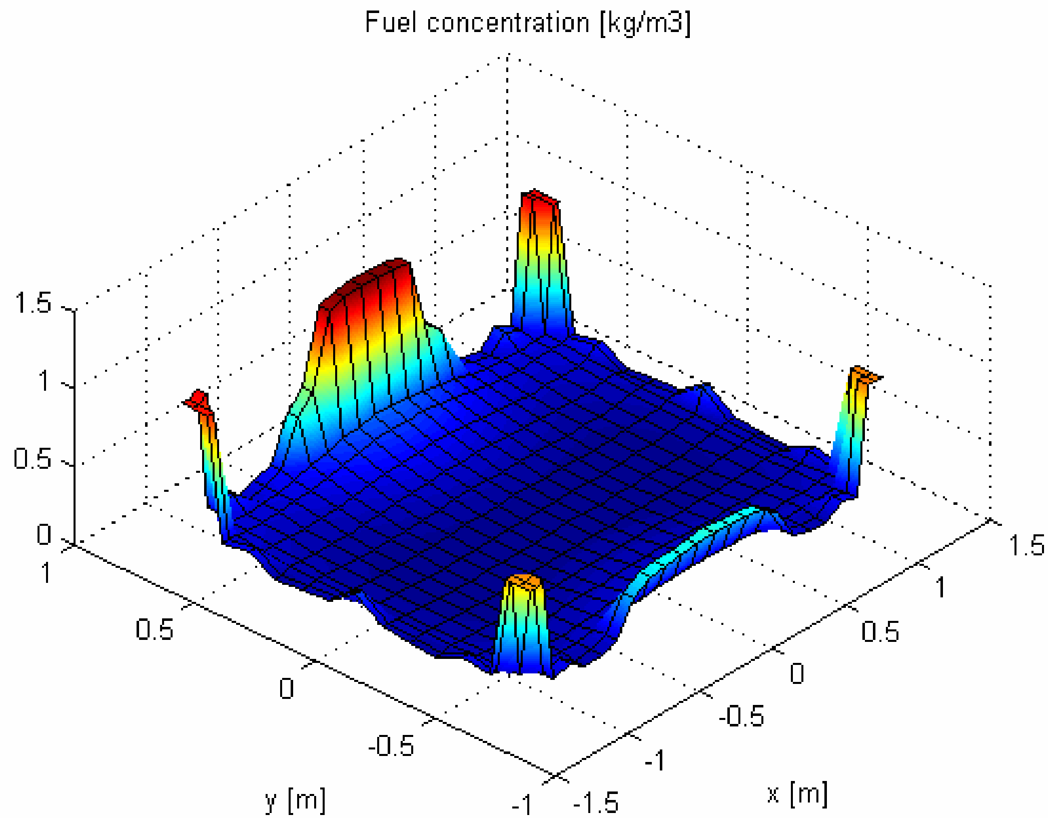


Fuel concentration in freeboard

Bituminous coal

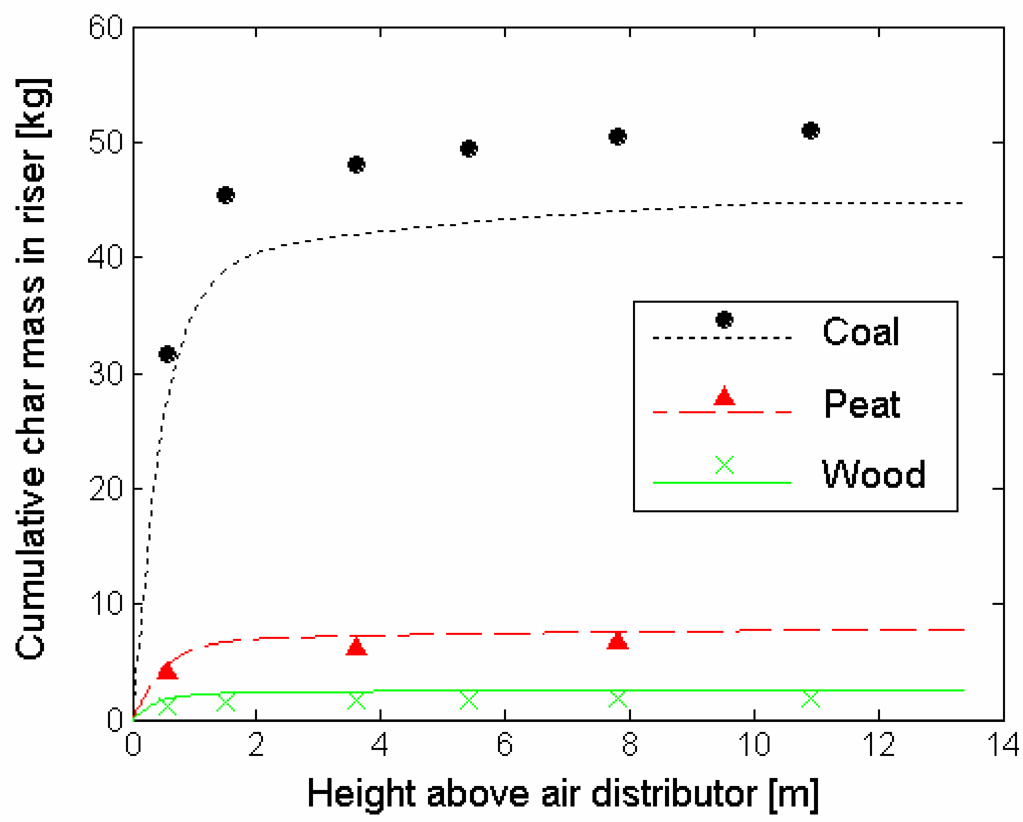
H= 7 m



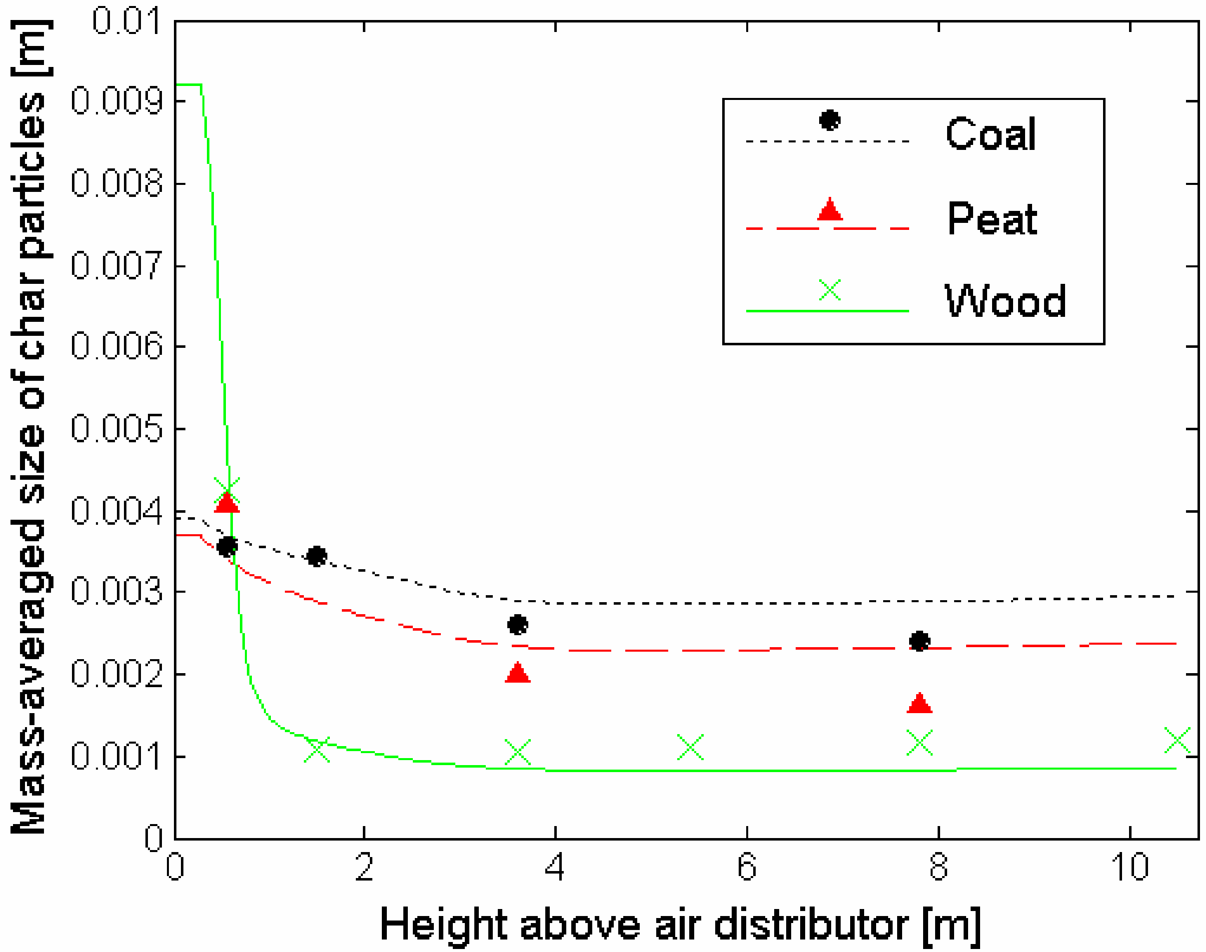


Axial distribution of char inventory

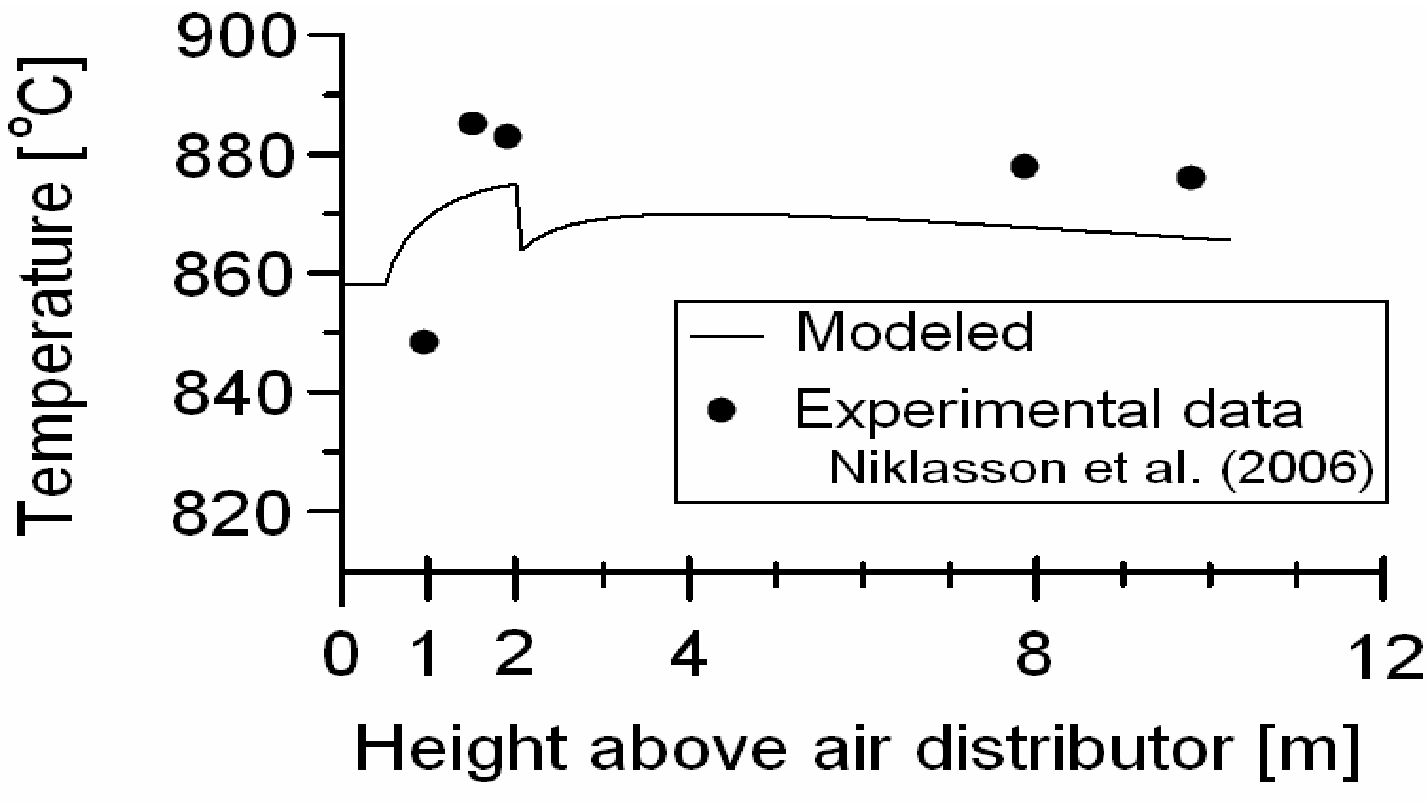
		Coal	Peat	Wood
Proximate (%)	Moisture	14.80	25.00	43.10
	Volatiles	31.36	49.97	46.10
	Char	47.24	22.03	10.40
	Ash	6.60	3.00	0.40
Ultimate daf (%)	C	79.8	59.5	50.6
	O	12.6	31.5	43.2
	H	5.3	6.4	5.9
	N	1.56	2.1	0.22
	S	0.72	0.53	0.04
LHV [MJ/kg ar]		29.0	20.8	17.6



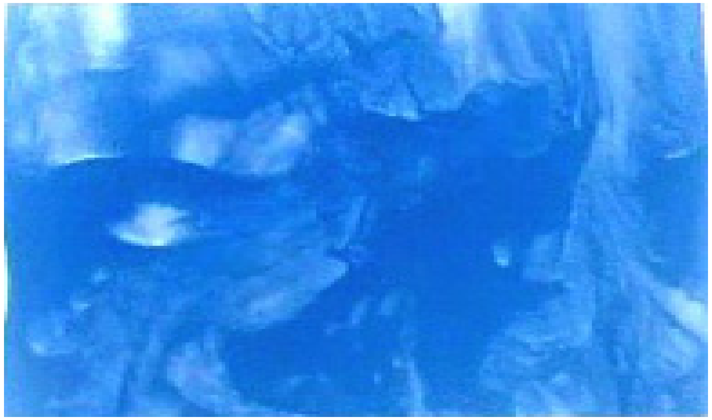
Axial distribution of fuel size



Temperature profile



Gas probes in CFB units



High-velocity oxidizing gas phase

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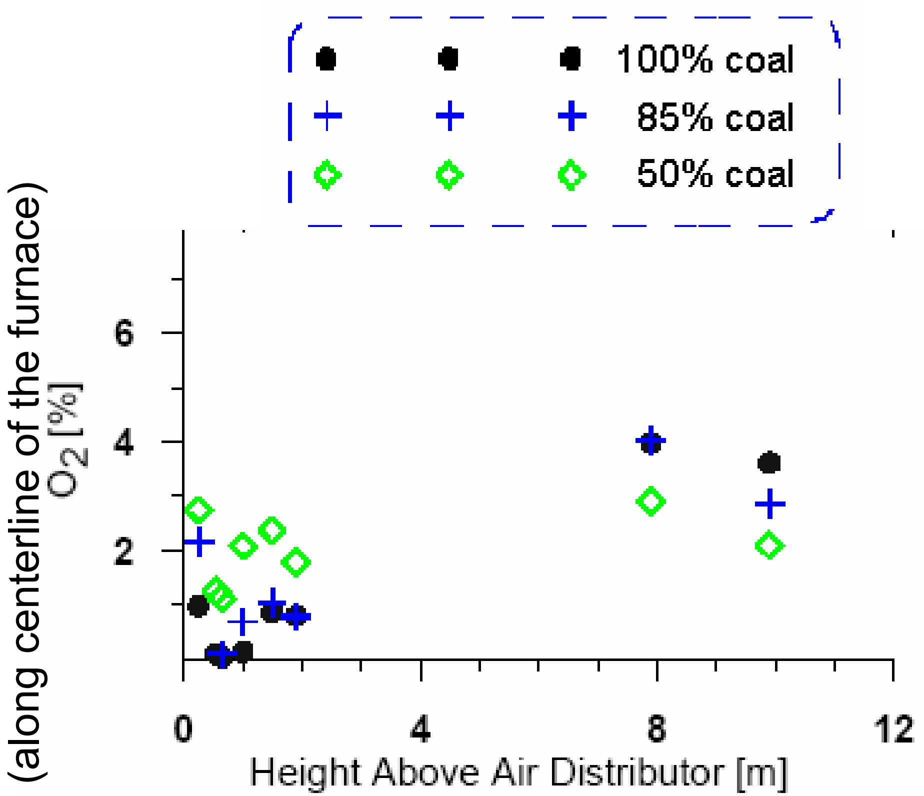
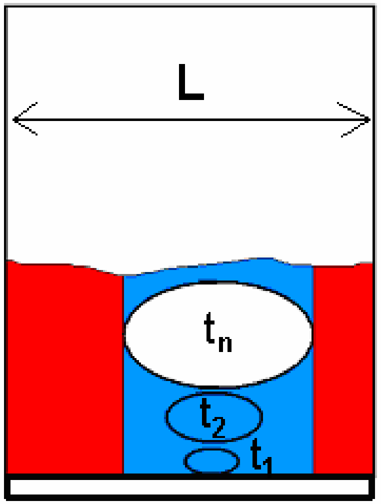
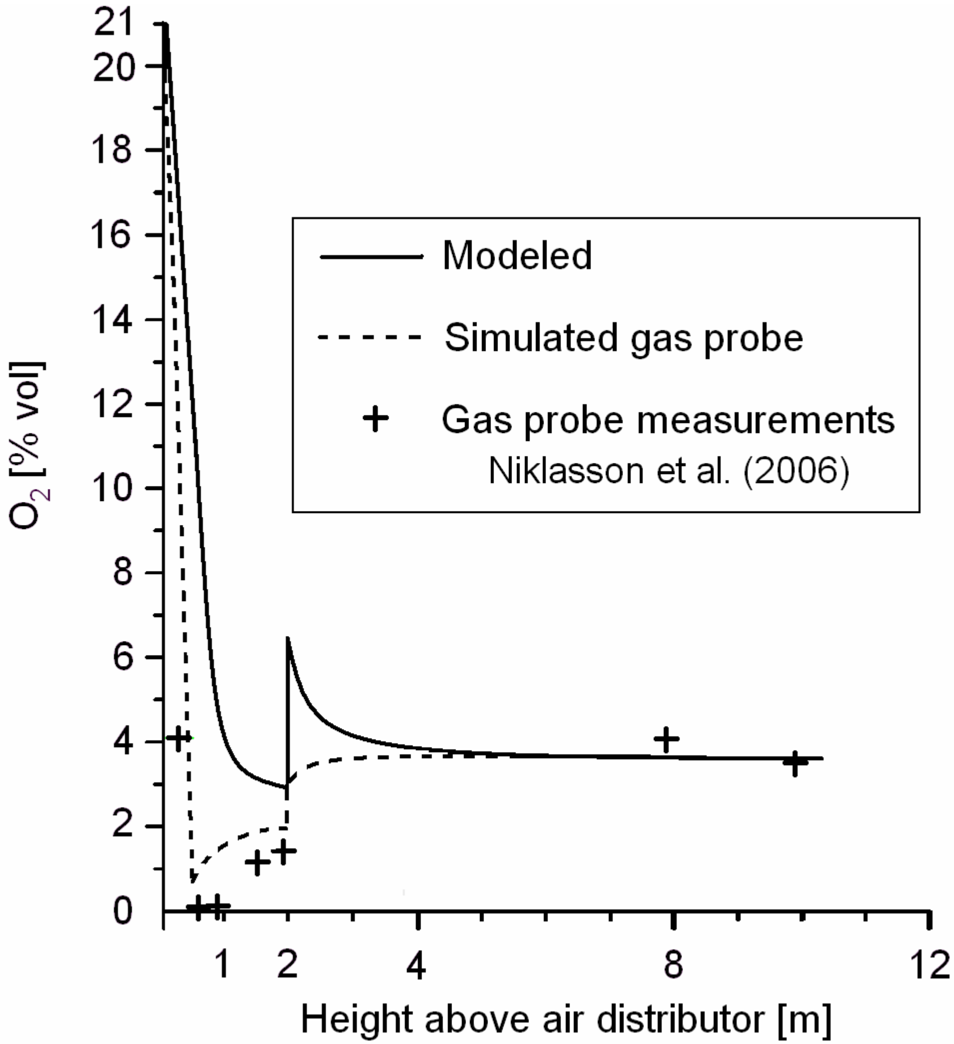
Low velocity reducing gas phase



Gas probe simulation





Further work

- Model steady-state PSD of bed material
- Enable several inert solid fractions
- Enable several fuel fractions
- Include kinetically-controled reactions
- Include heterogeneous reactions

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