Modeling of large-scale CFB boilers
- an update of the Chalmers activities

David Pallarès

Filip Johnsson

Dept. of Energy and Environment
Div. of Energy Conversion

Chalmers University of Technology

Outline of presentation

Overall CFB models

- Gas mixing
- Heat transfer
- Emissions
- …
- **Solids mixing**
  - Inert solids mixing
  - …
  - **Fuel mixing**

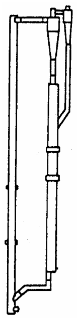
Aims of overall CFB modeling

- Comprehensive
- Universal
- Entire CFB loop
- Consistent operation-directed I/O scheme
- Reasonable calculation time
- Several solid fractions and their PSD's

Scope: Large-scale CFB units

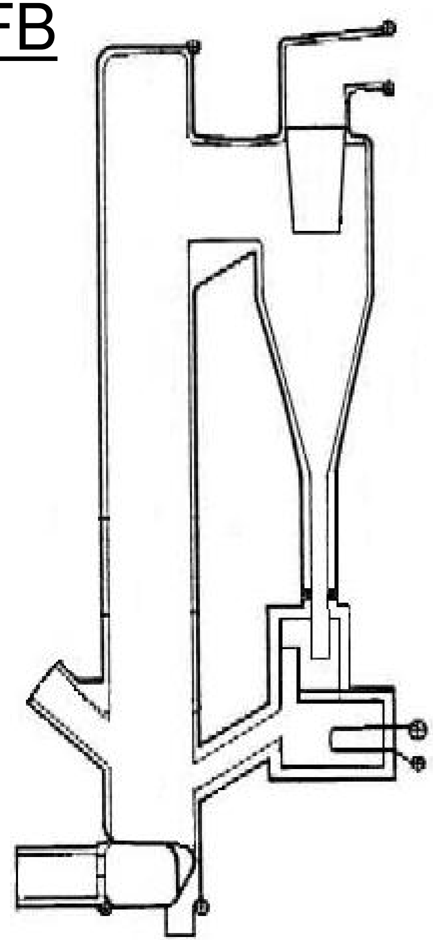
Laboratory CFB

- Pharmaceutics
- Coating
- Cracking
- …



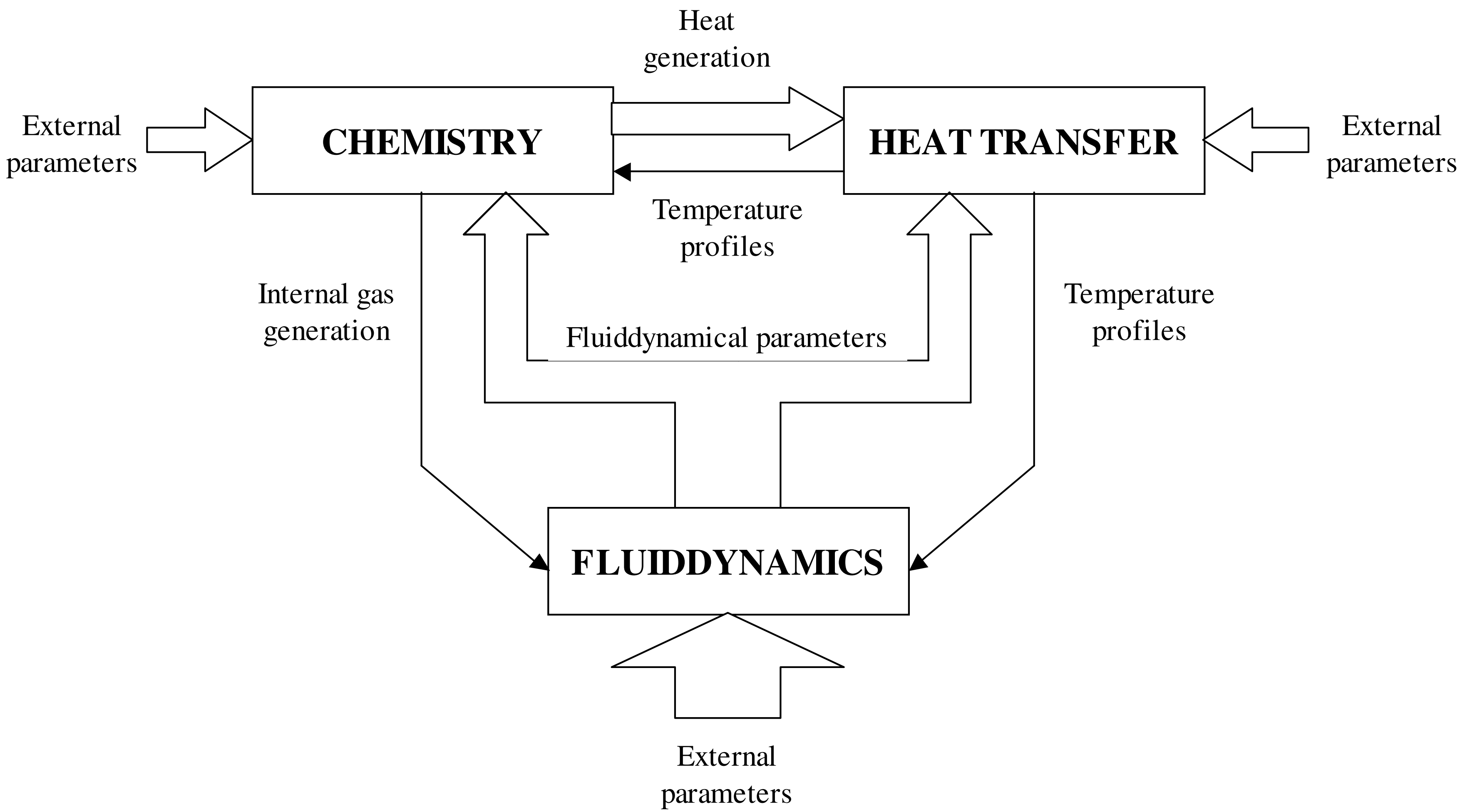
Large-scale CFB

- Combustion
- Gasification

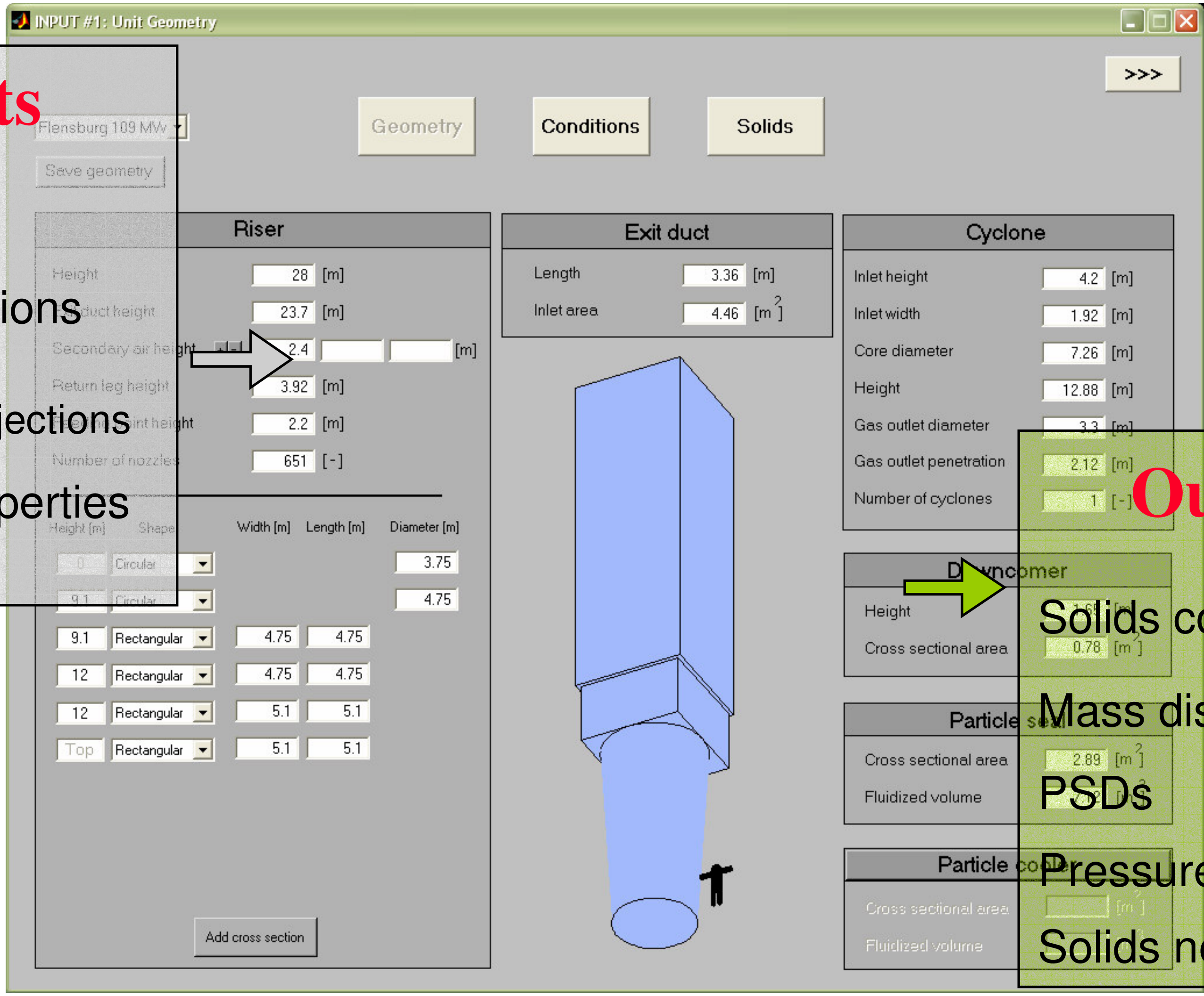


>20	H_0 / D_e	<10
>1	$H_{b,\, fixed} / D_e$	<1
>50	G_s [kg/m²s]	0.5÷20
A-B	Solids group	B

CFB modeling fields



Modeling of fluiddynamics



Inputs

1) Geometry

2) Op. conditions
- Δp_0
- Gas injections

3) Solids properties

Outputs

Solids conc. & vel.

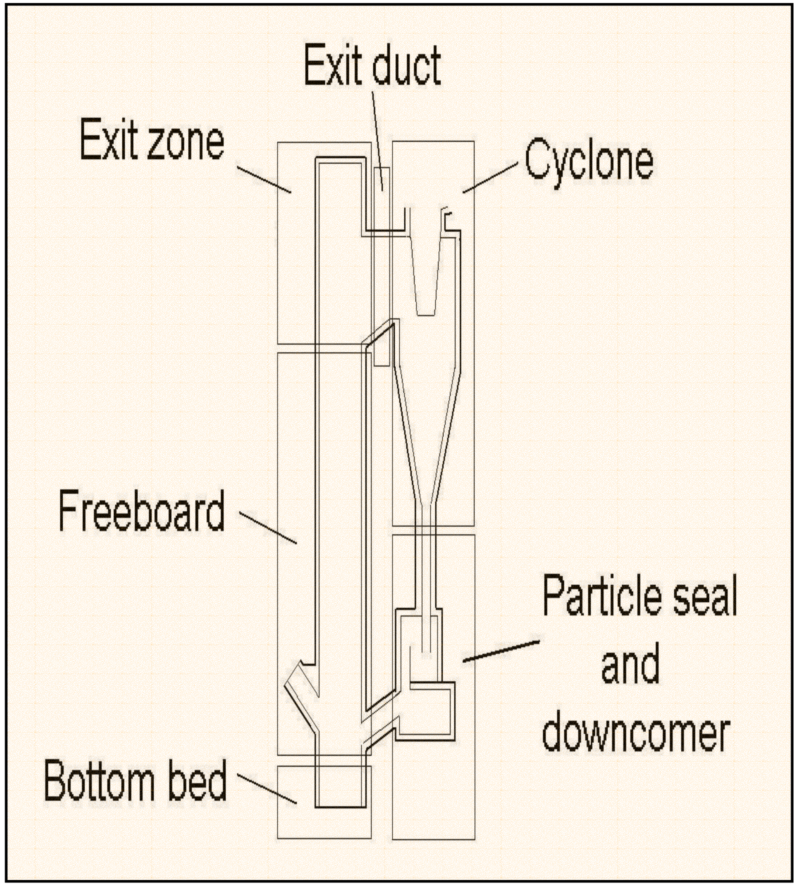
Mass distribution, τ

PSDs

Pressure profiles

Solids net flow

Submodels used



1 Two-phase flow theory adapted to CFB

2
- Cluster and dispersed solid phases
- Core/annulus flow structure
- Particle interactions

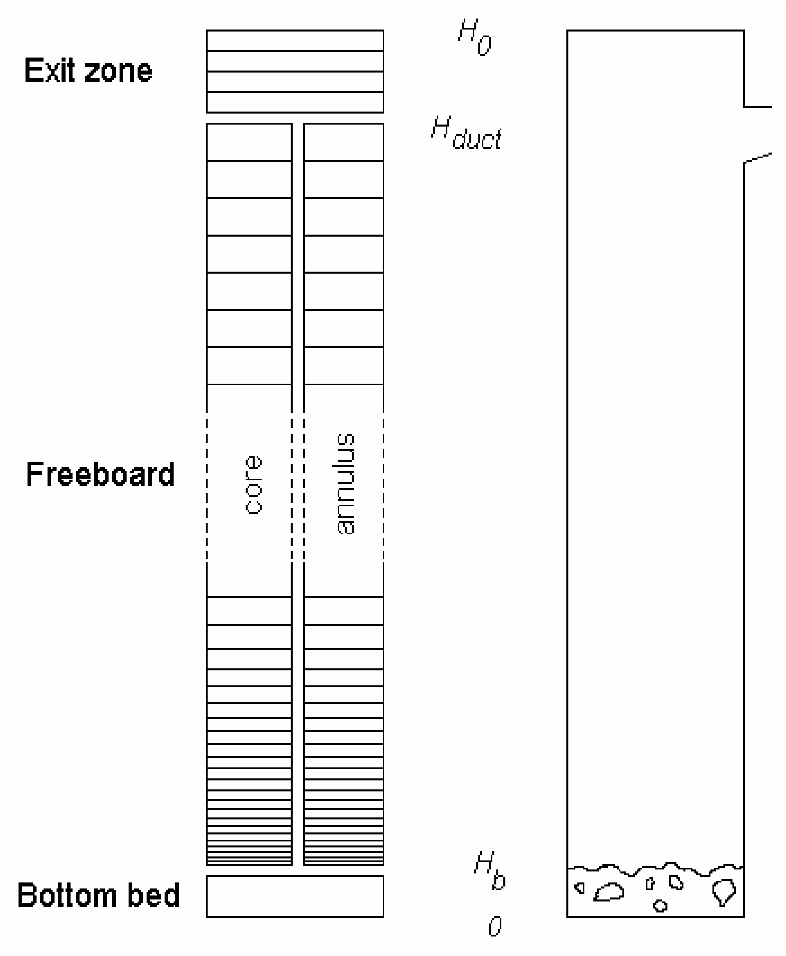
3
- Ballistic movement
- Backflow effect (correlation)

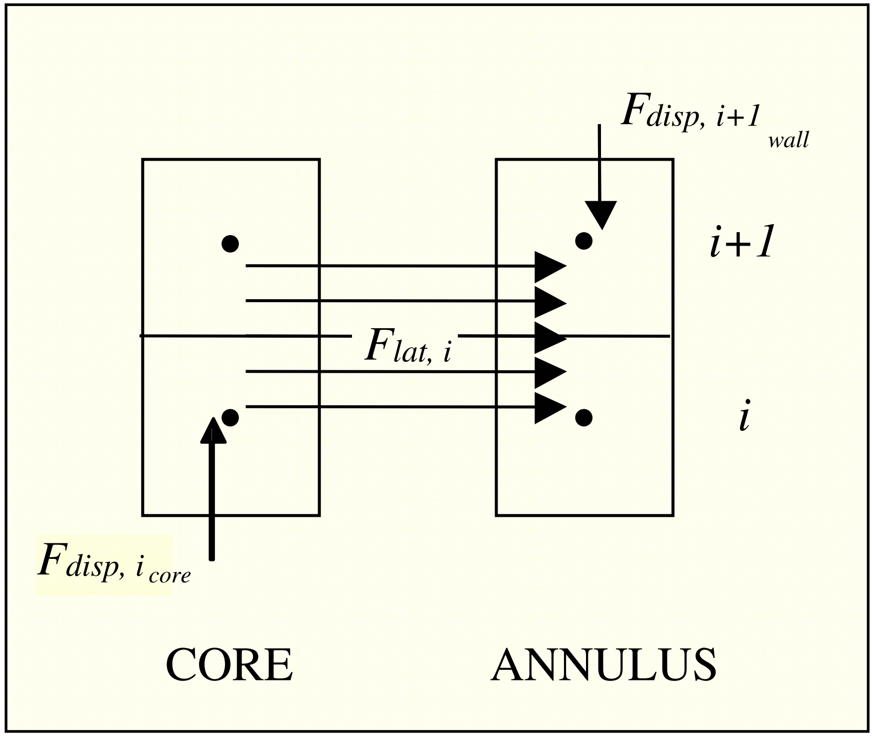
4 Acceleration effects

5 Separation efficiency & pressure drop

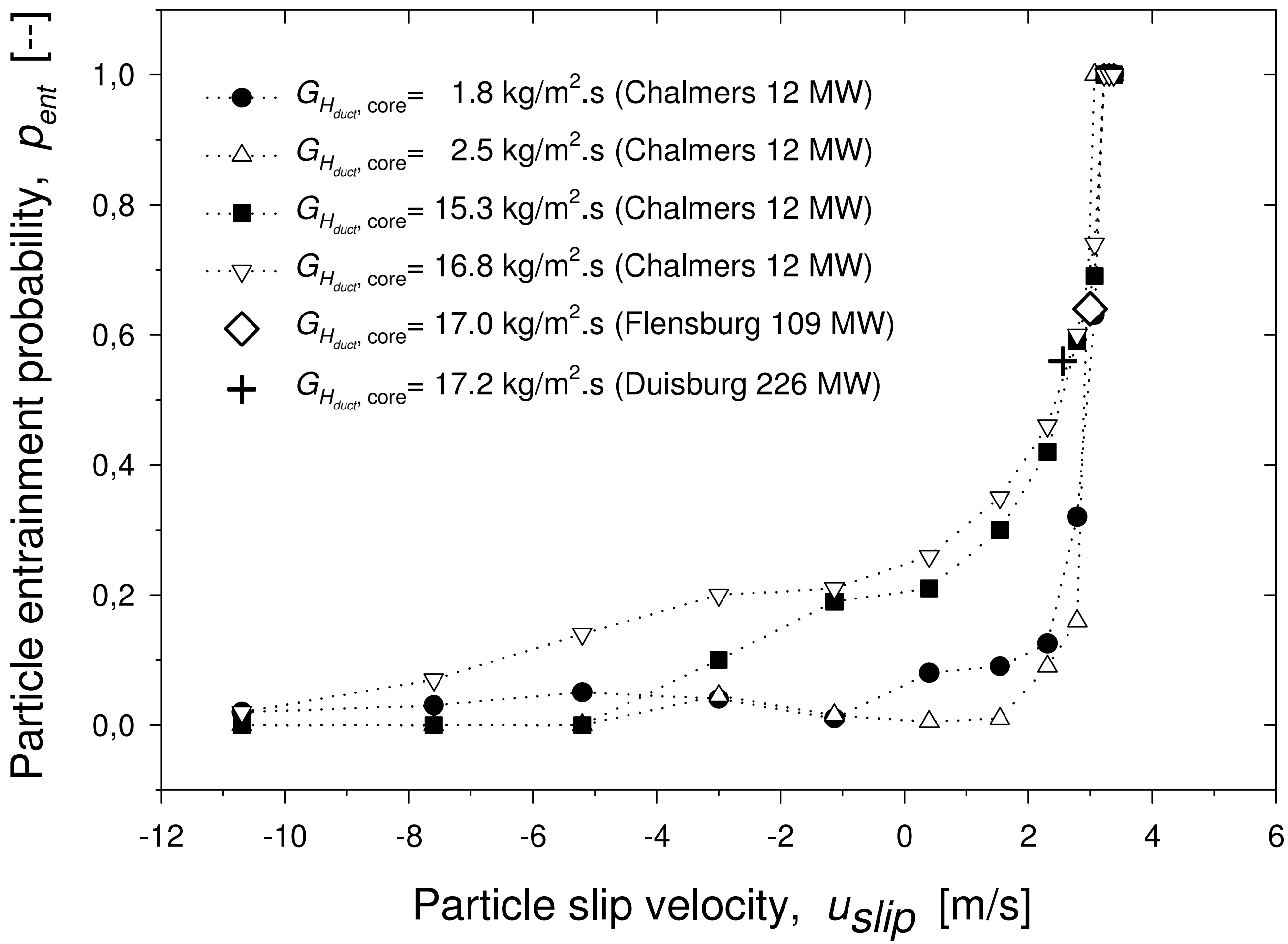
6 Two-phase flow theory adapted to SFB

Riser mesh

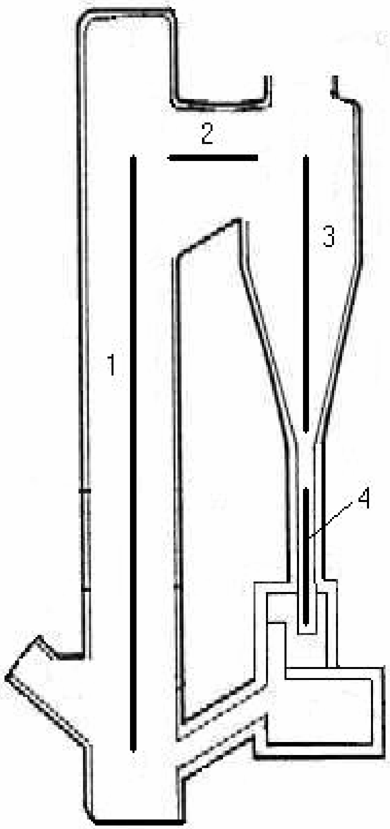

Exit zone
Freeboard
Bottom bed
core
annulus
H_0
H_{duct}
H_b
0


$F_{disp,\ i+1}$ wall
$i+1$
$F_{lat,\ i}$
i
$F_{disp,\ i}$ core
CORE
ANNULUS

Exit zone – Backflow effect



Return leg – Pressure balance



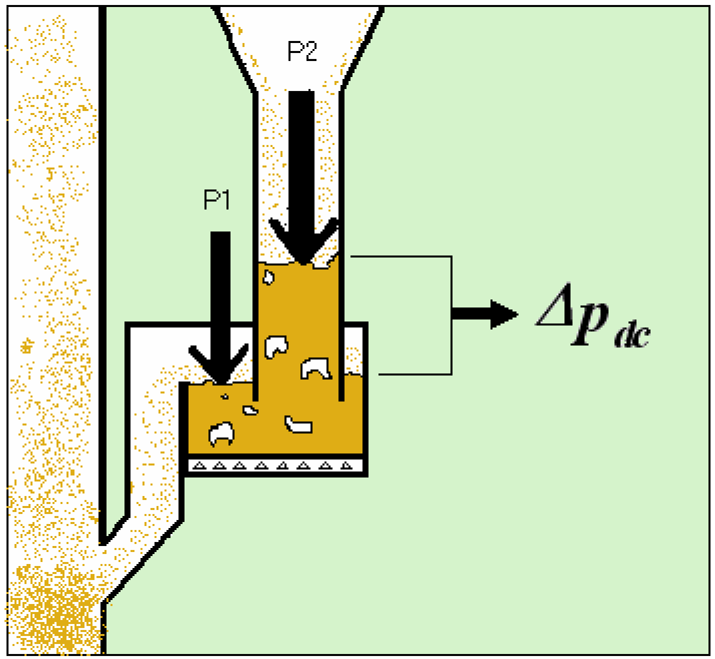
Criteria

1) $\Delta p_{refeed} < 0$

2) $\Delta p_{duct} < 0$

3) $\Delta p_{cycl} < 0$

4) $\Delta p_{dc} > 0$



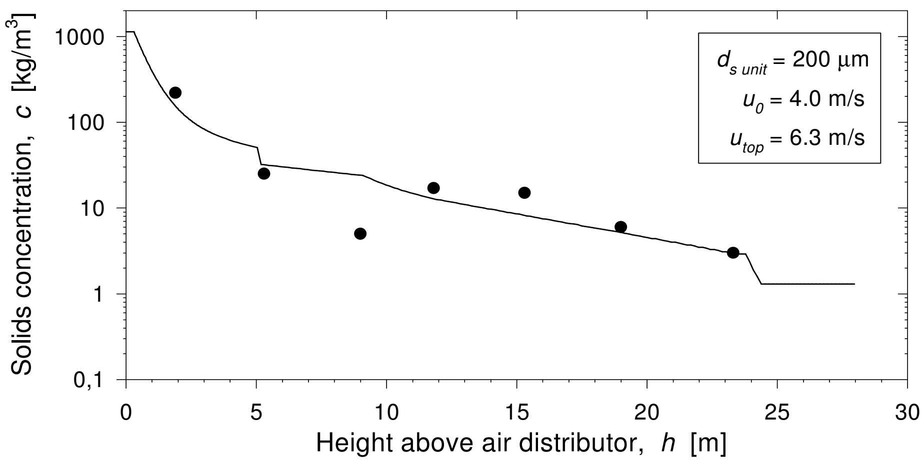
Model results (solids mixing)

vs

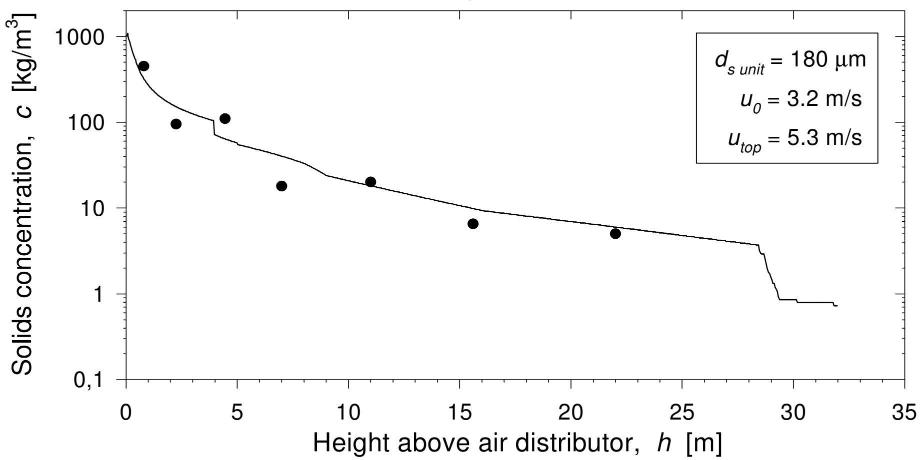
Experimental data

Solids concentration profiles

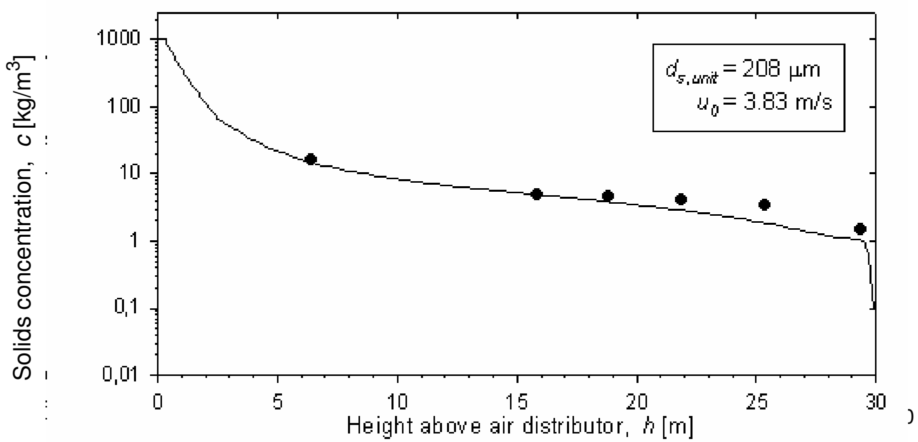
Flensburg 109 MW CFB



Duisburg 226 MW CFB

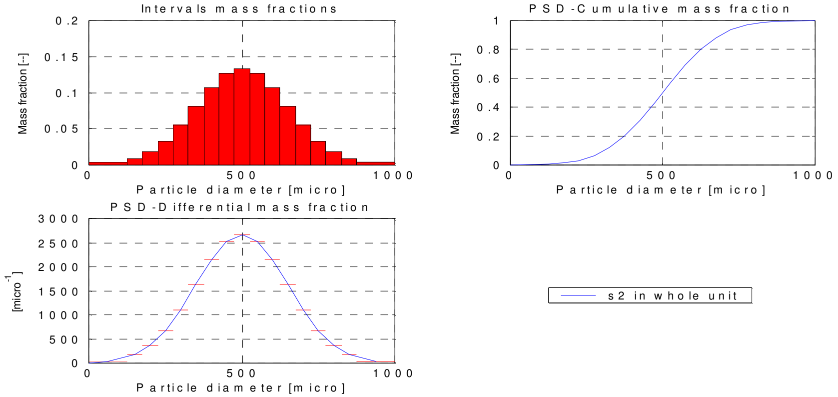


Örebro 165 MW CFB

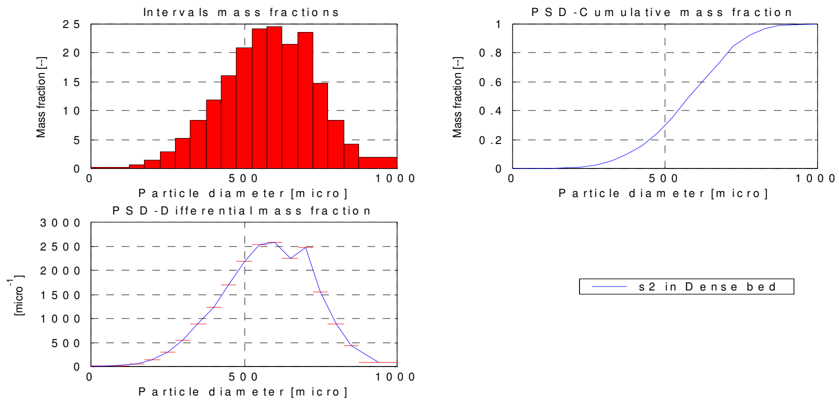


PSD evolution

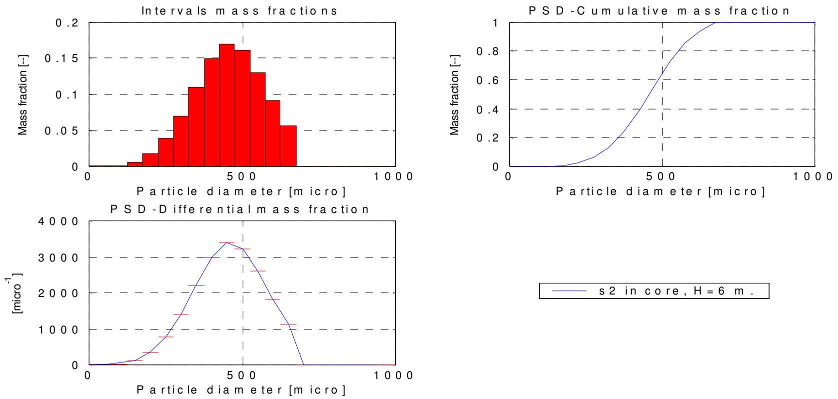
Unit (input)



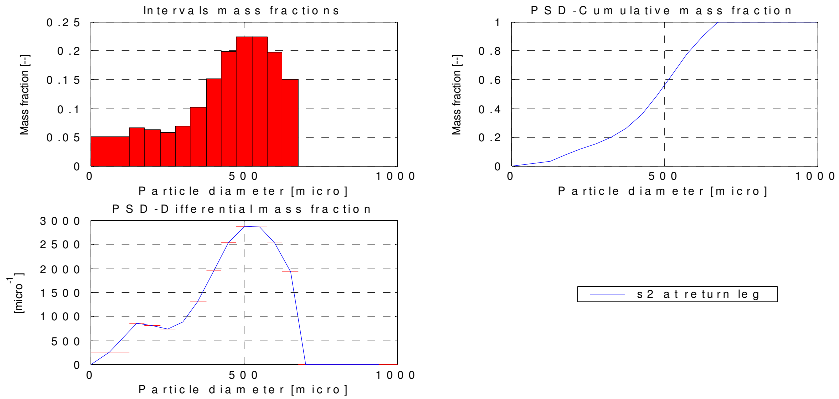
Dense bed



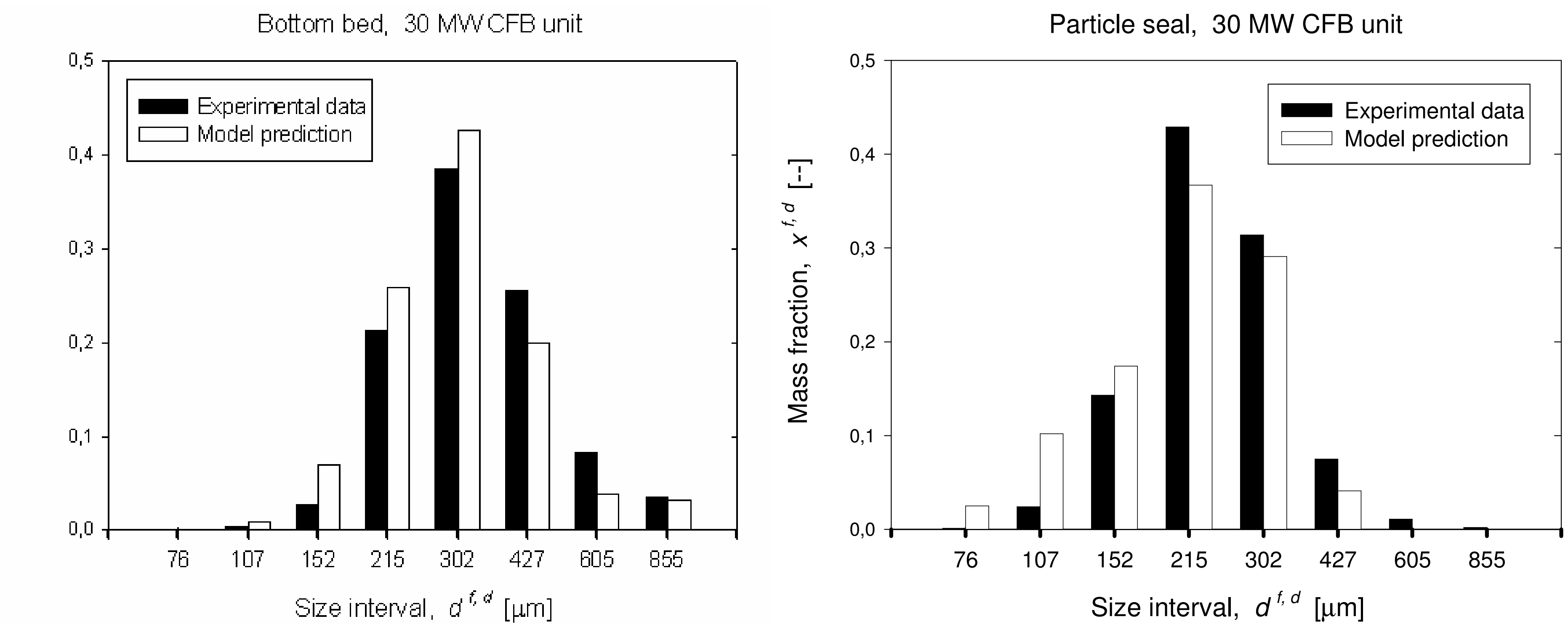
Freeboard (Core, h=6 m.)



Particle seal



PSD evolution



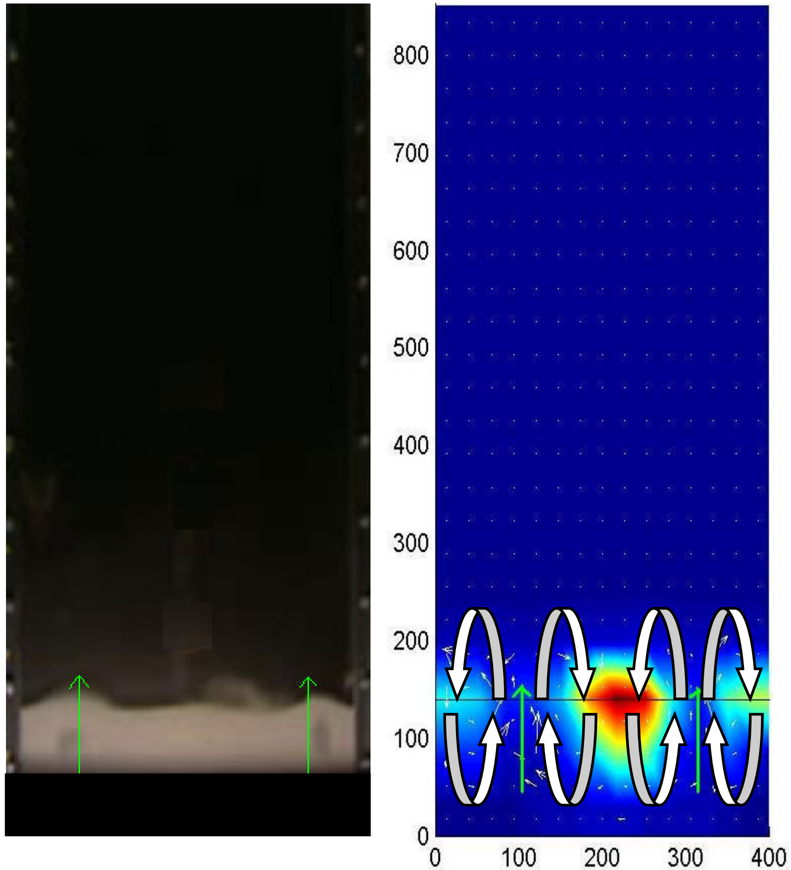
Ongoing work

Modeling of fuel mixing and conversion

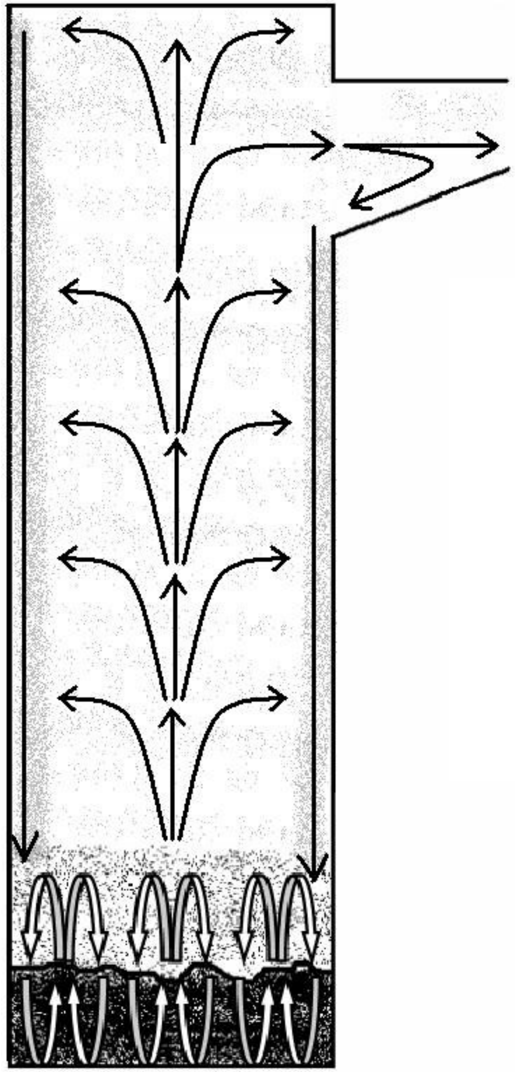
- Phisycal properties changing continuously due to particle conversion: d_p, ρ_f, $u_t = f(t)$

- Horizontal gradients $\rightarrow$ 3-dimensional

Fuel mixing experiments

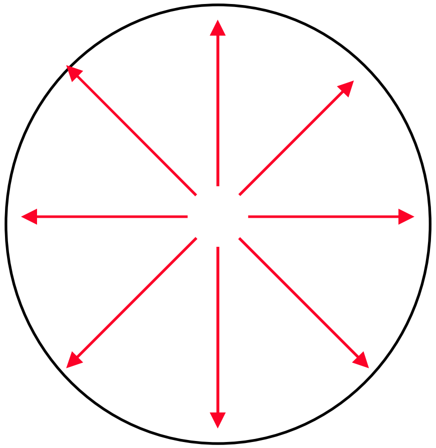


Model for fuel mixing

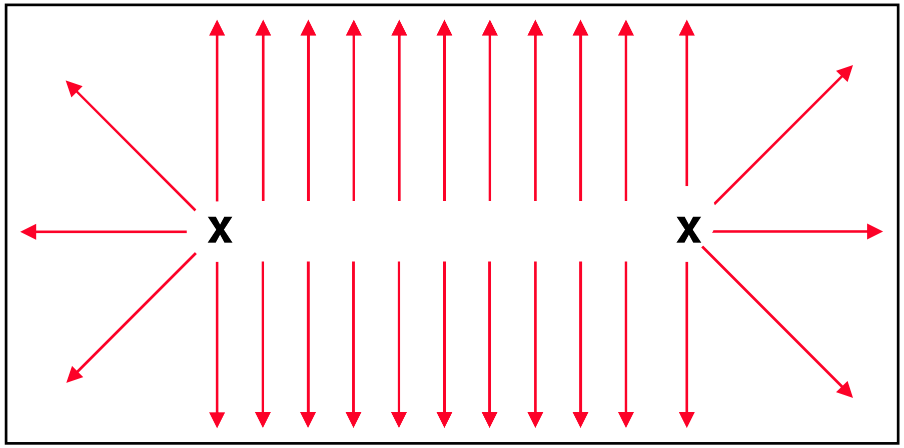


	Vertical	Horizontal
Disperse phase	Core-annulus Exponential decay, *K*	Core-annulus Lateral differential flow
Cluster phase	Ballistic Exponential decay, *a*	Assumed diffusion
Bottom bed	Perfect mixing	Assumed diffusion

Assumption for disperse phase



Circular
cross section



Rectangular
cross section

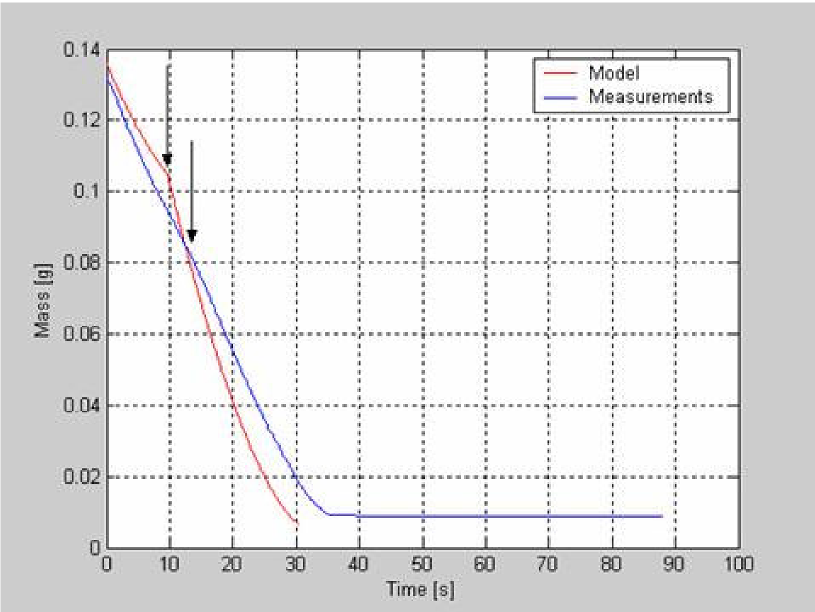
Model for fuel conversion

Main assumptions

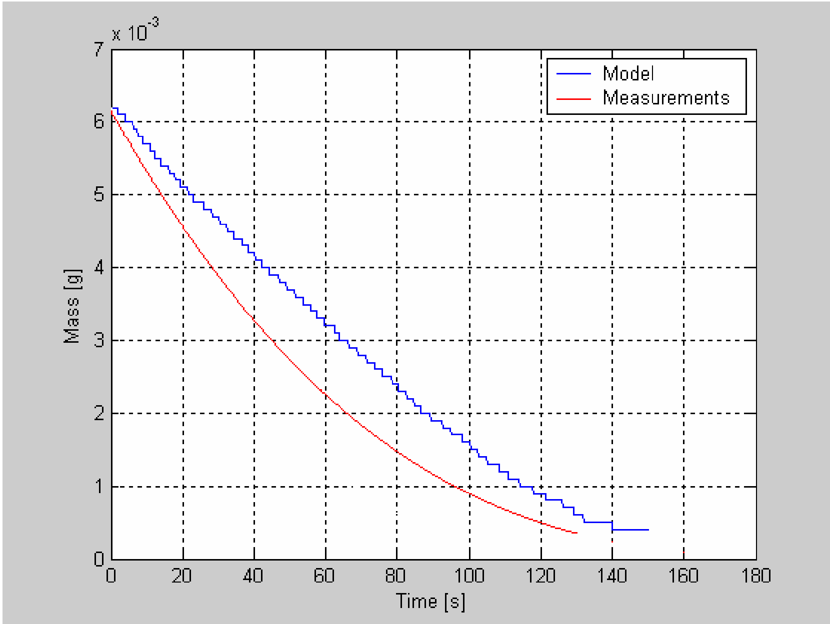
- Fuel particle approximated to an ideal geometry (∞-plane, ∞-cylinder, sphere)
- Quasi-steady state
- Convection term shown to be neglectable

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

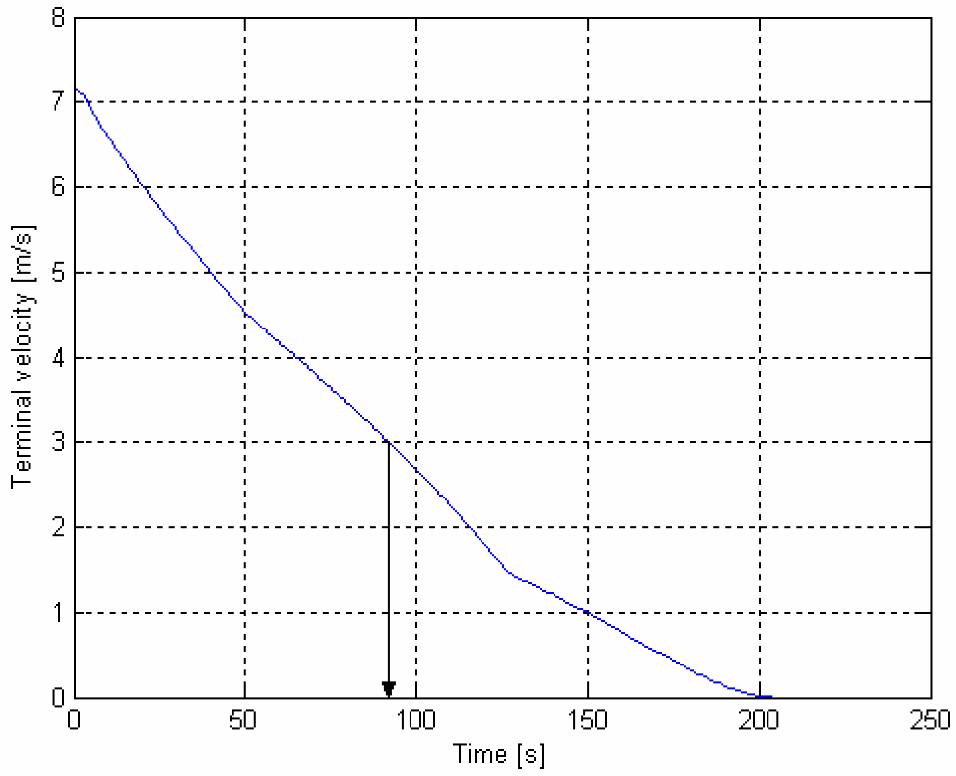
T = 800 C



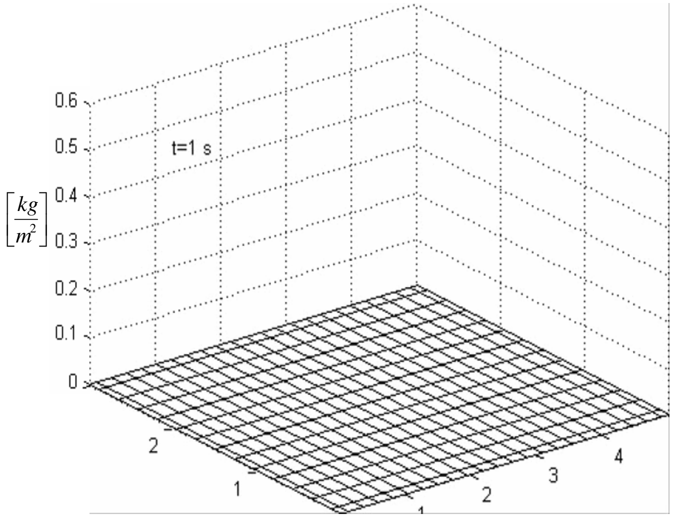
C_{o2} = 6%



Continuous feeding as sum of batches

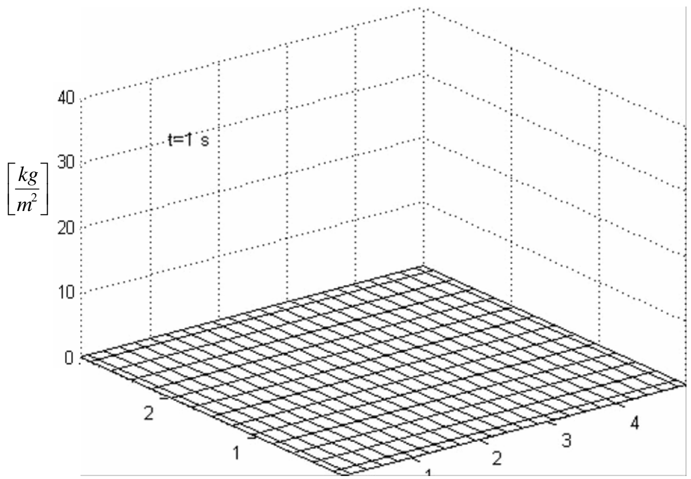


Batch

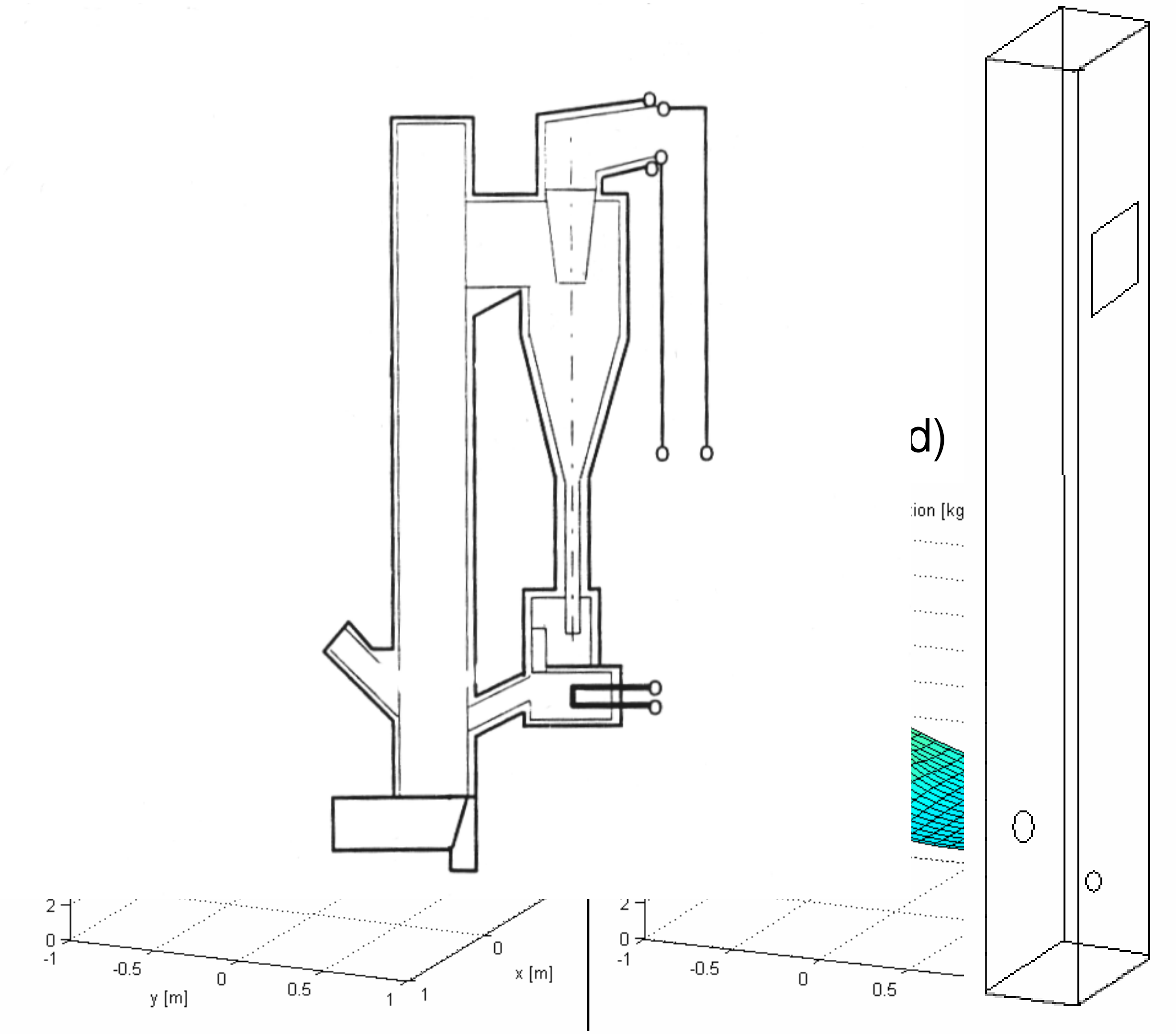


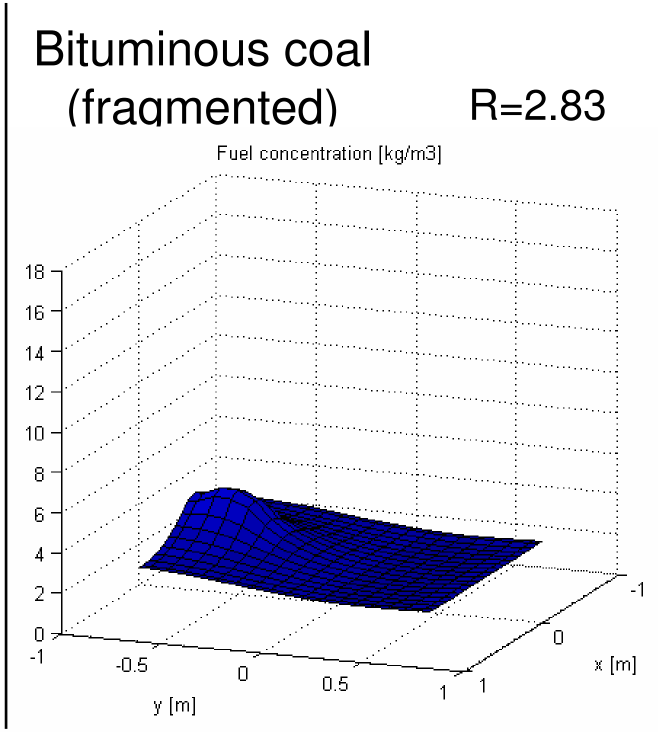
Continuous feeding as sum of batches

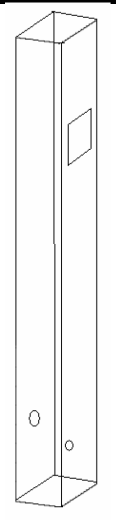
Sum of time-delayed batches



Fuel concentration in bottom bed



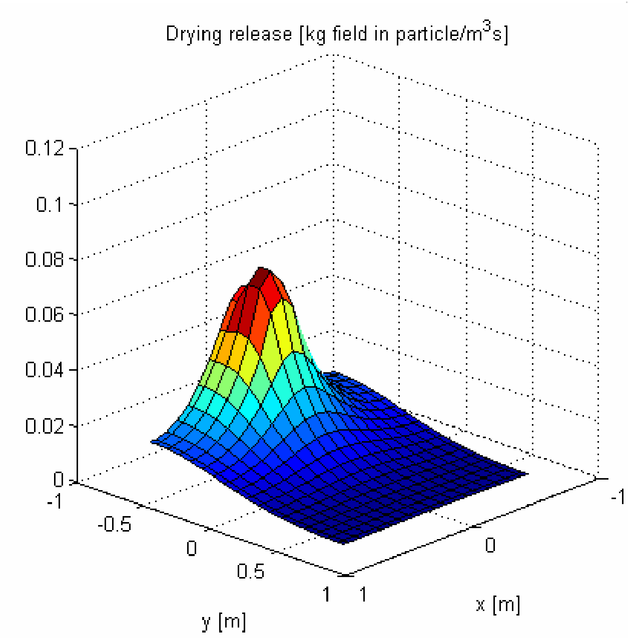




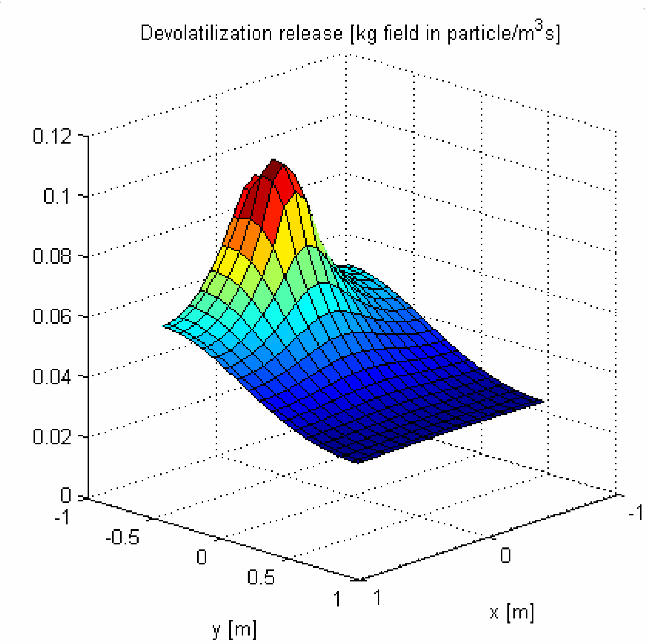
Fuel releases in bottom bed

Unfragmented bituminous coal case

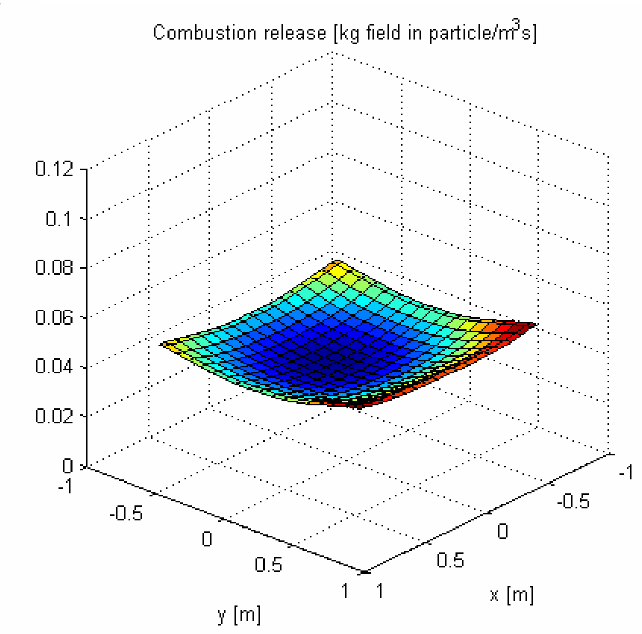
Moisture



Volatiles



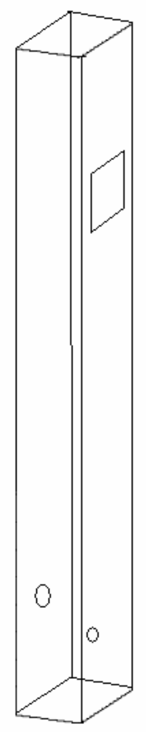
Char

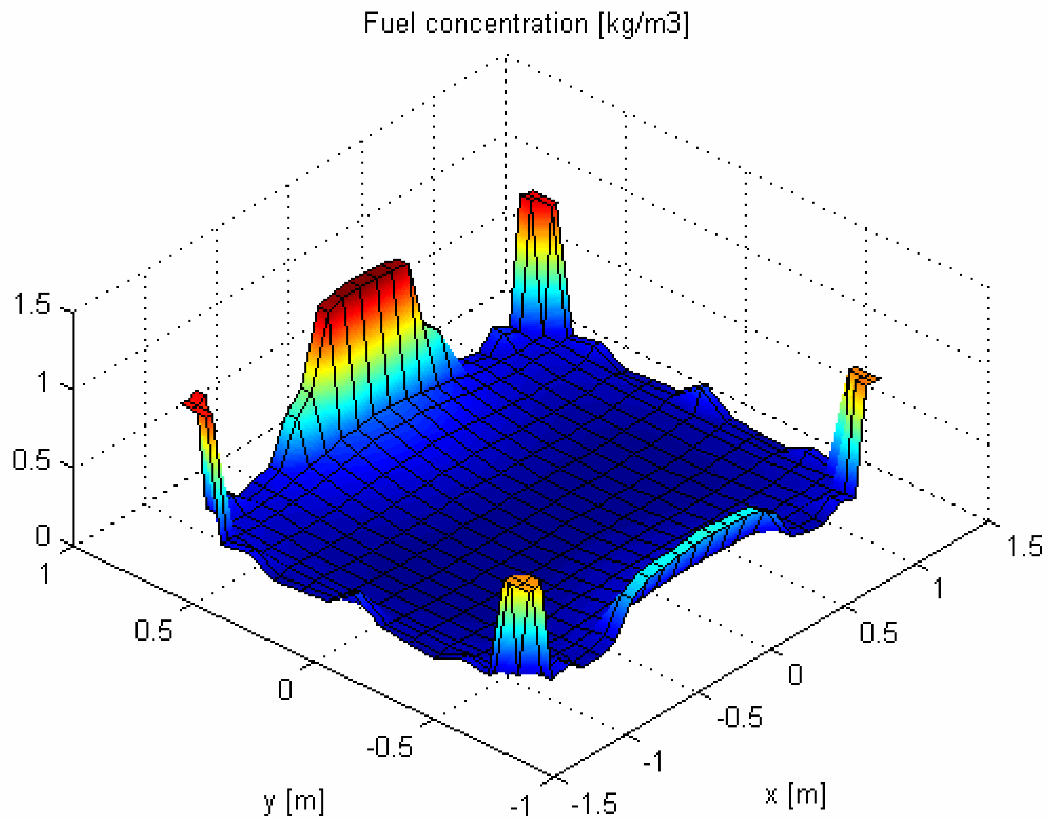


Fuel concentration in freeboard

Bituminous coal

H= 7 m





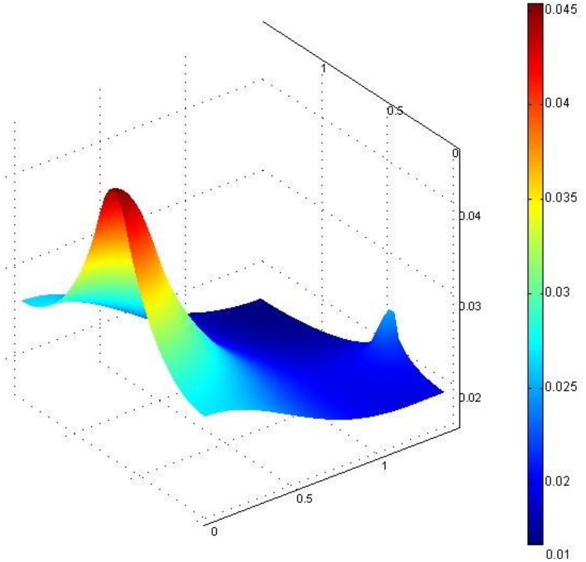
Model vs Experiments

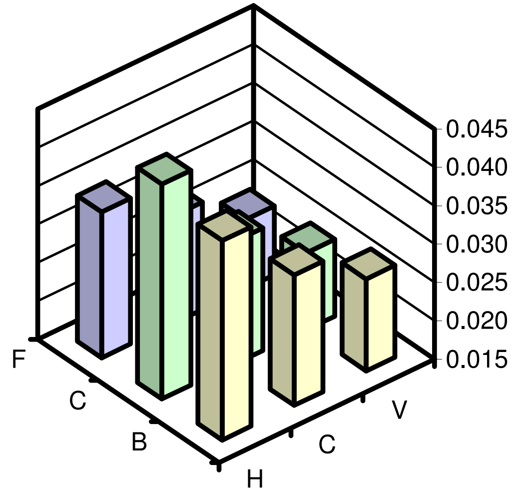
u_0 = 3.81 m/s

m_{fuel} = 0.303 kg/s

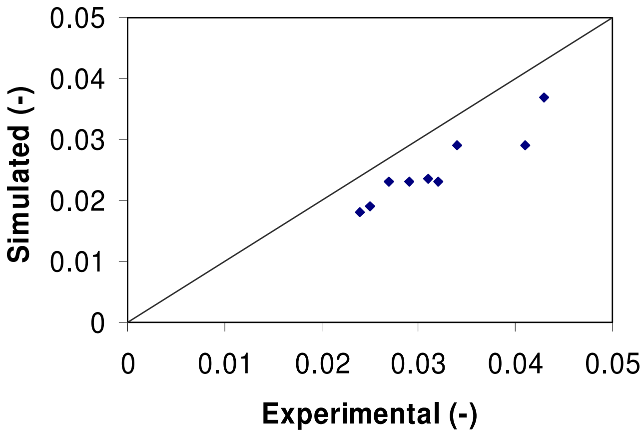
P = 9.43 MW

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



Acknowledgements

- This work is sponsored by the Swedish National Board of Energy Administration and Kvaerner Power (in separate projects)

David Pallarès david.pallares@chalmers.se

Filip Johnsson fijo@chalmers.se

Department of Energy and Environment www.entek.chalmers.se

Chalmers University of Technology www.chalmers.se

Fragmentation

t_{frag}= 13 s

N_{frag}= 2