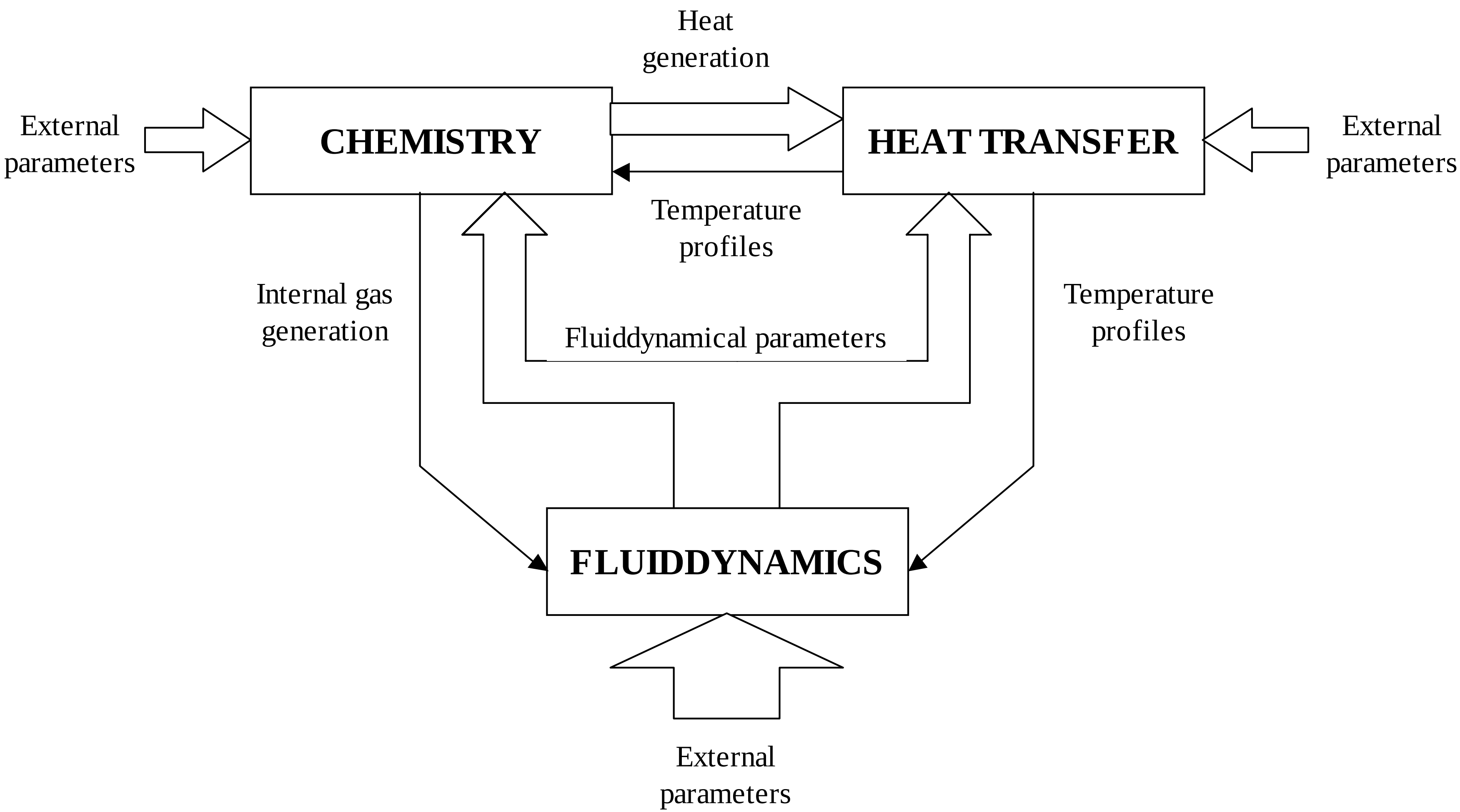
Mixing and flow structures in fluidized bed boilers

Filip Johnsson
Department of Energy Conversion
fijo@entek.chalmers.se
+46 31 772 1449

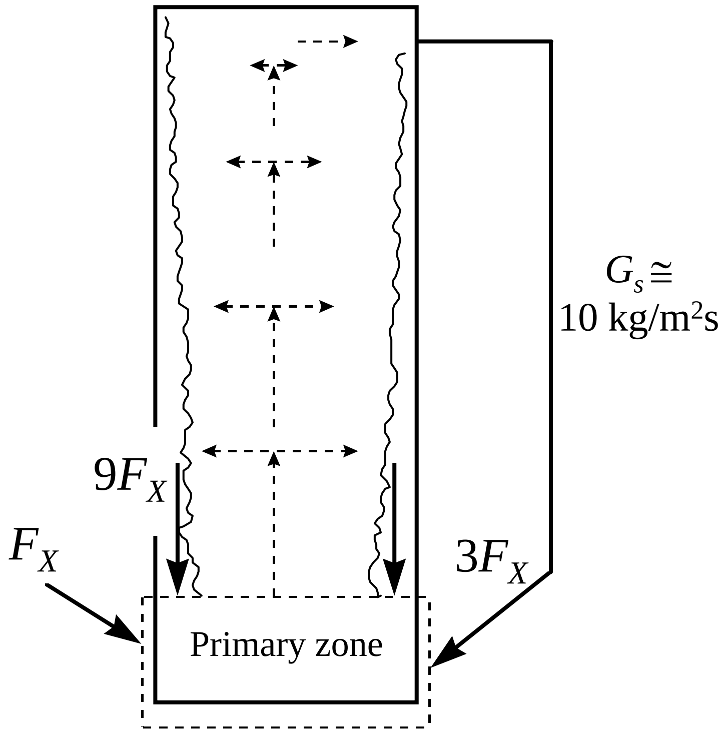
47th IEA meeting on FBC, Technical meeting
Zlotniki, Poland, October 13, 2003

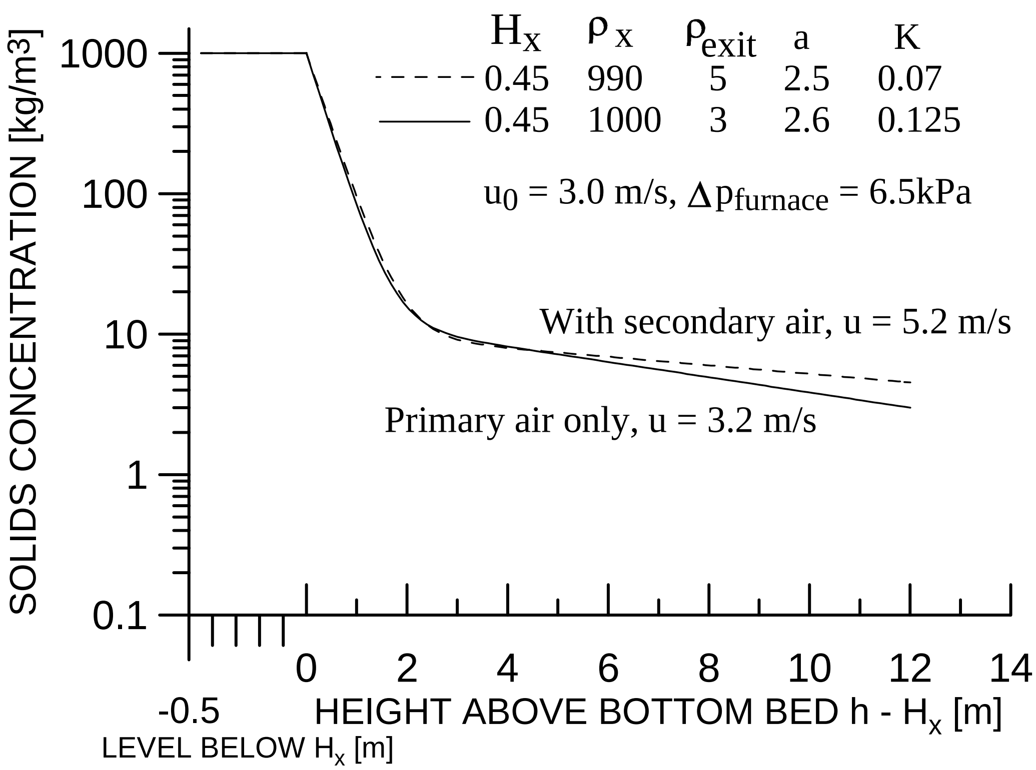
CFB modelling



Overall flow picture – time average

(as obtained from Chalmers 12 MW CFB boiler and cold units)





CFB boilers:

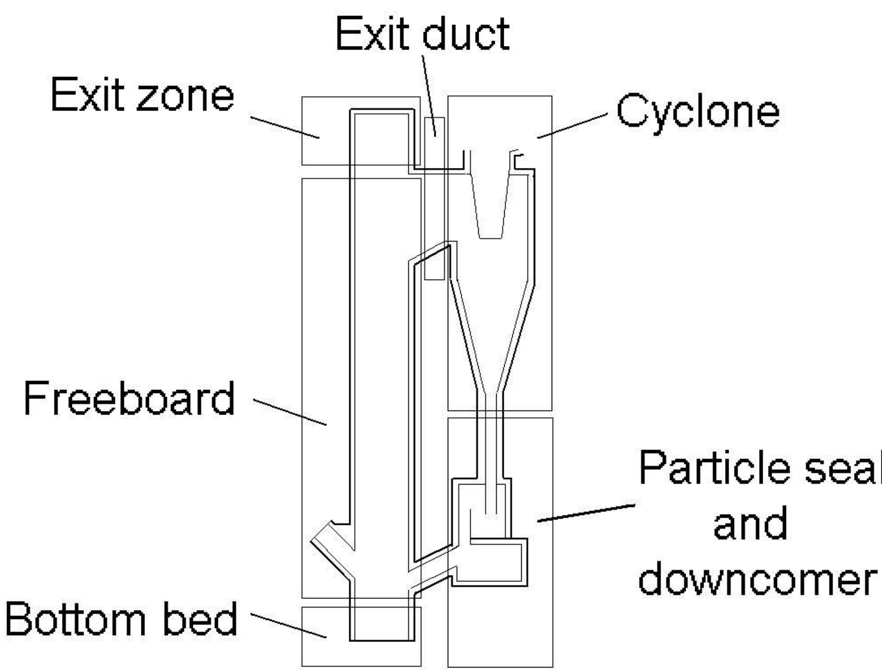
$H_0 / D_e < 10$

$0 < H_{b,\ fixed} / D_e < 1$

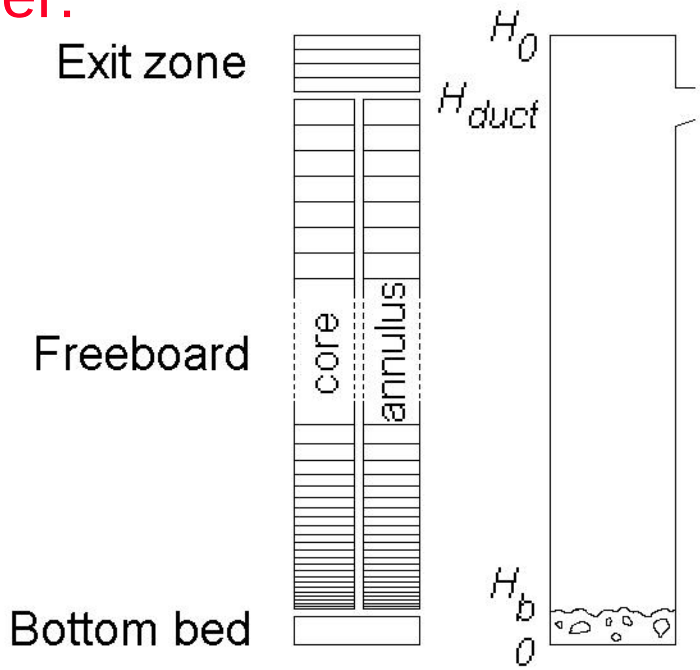
Group B solids

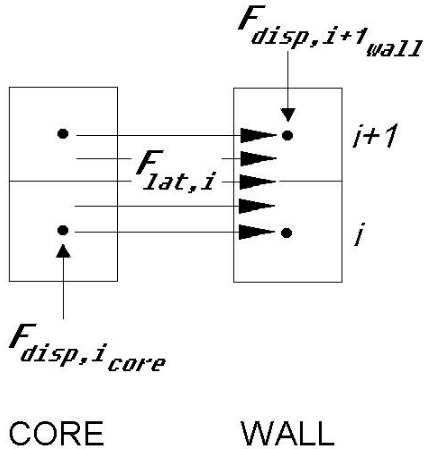
$0.5 < G_s < 20$ kg/m²s

Modeling zones



Riser:





Inputs

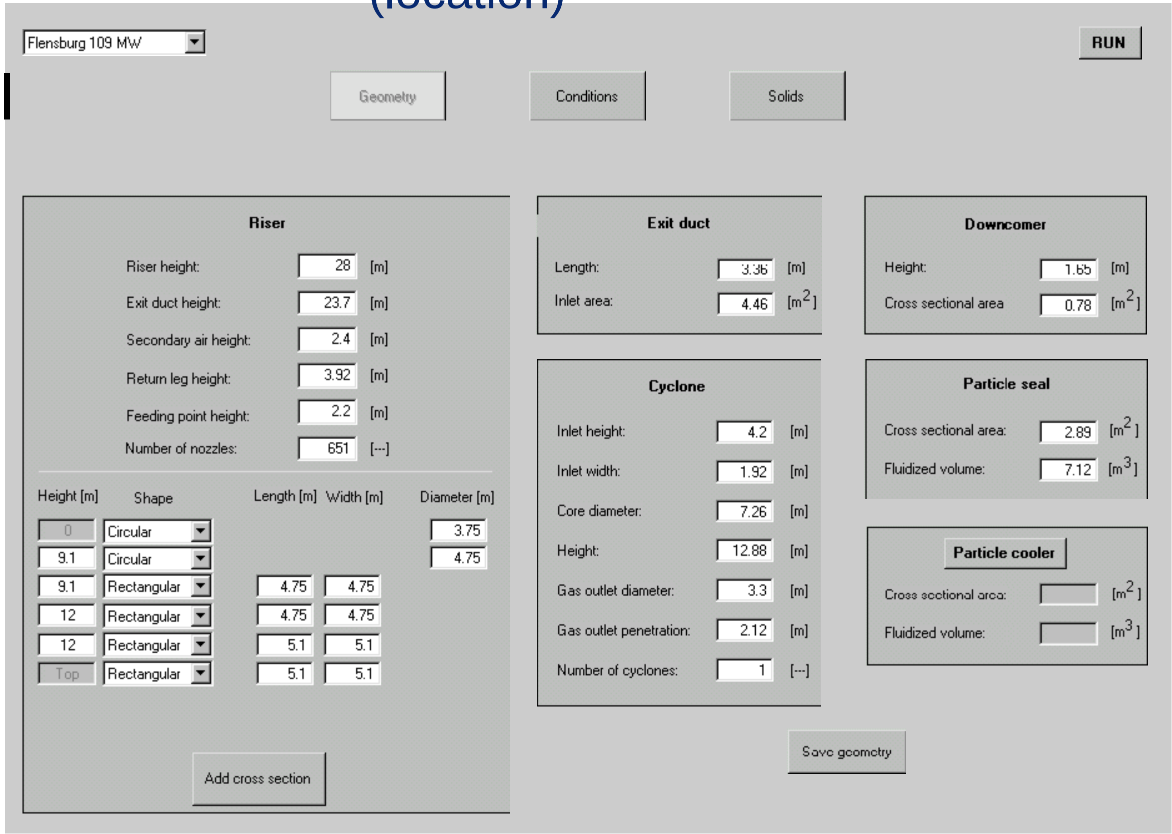
- Geometry
- Solid properties (for each solid fraction)
- Operational conditions (u_0, q_{sec}, Δp)
- Solids flux is an output!

Outputs

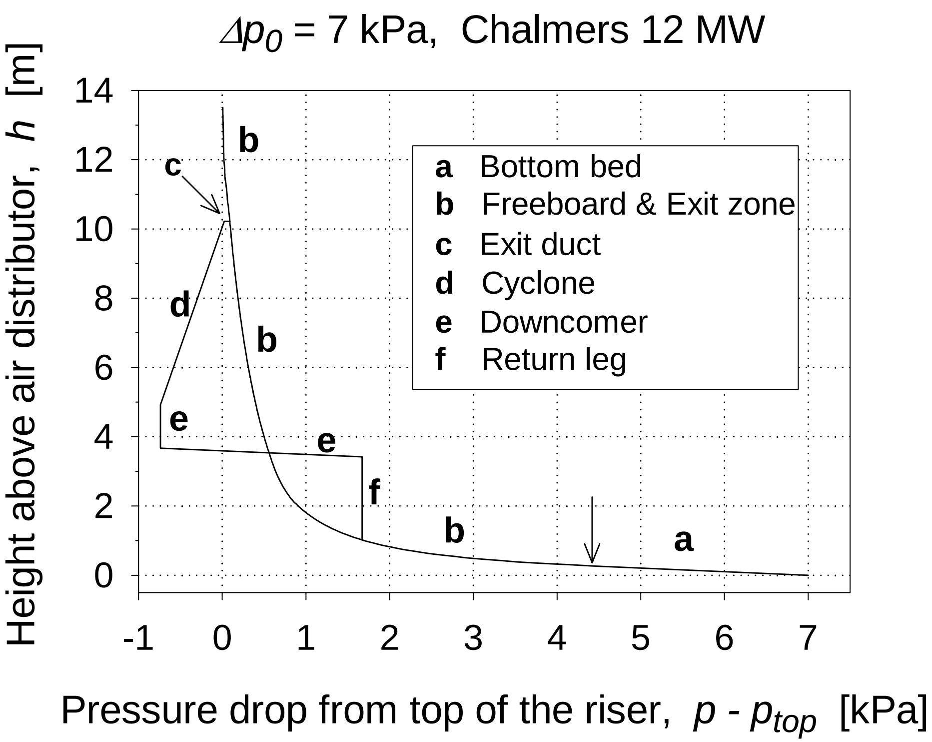
- Concentration and velocity of solids (location, size interval, solid fraction)
- Gas flows
- Mass, particle size distribution, pressure drop (location)

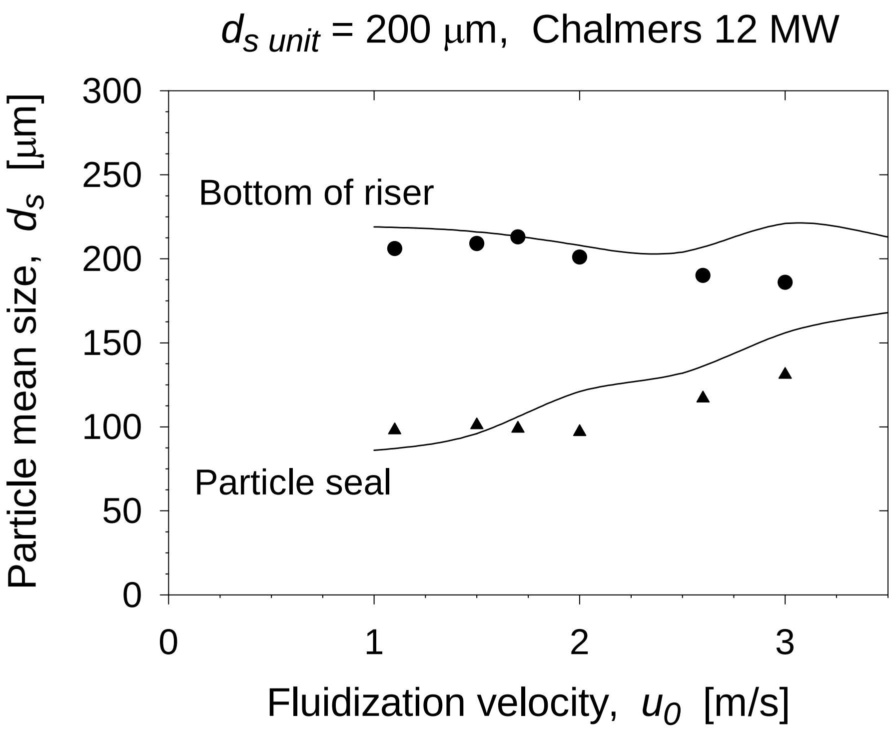
The Chalmers model

Graphical User Interface (example)



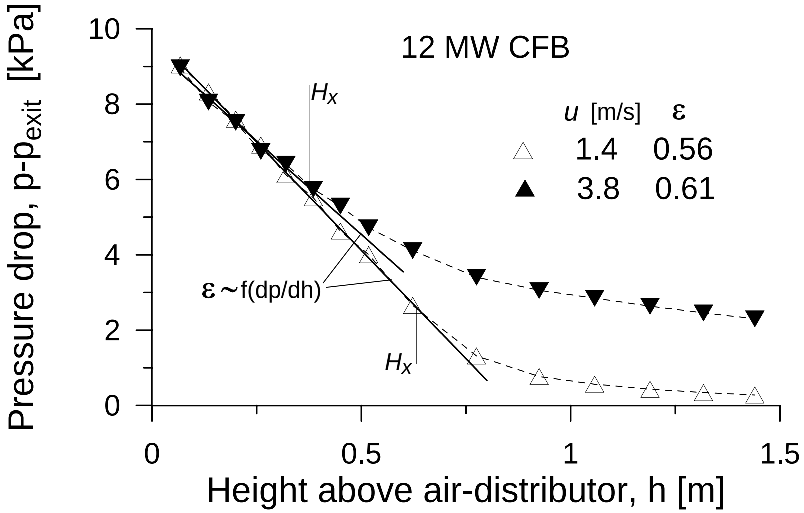
Example of results – the Chalmers model

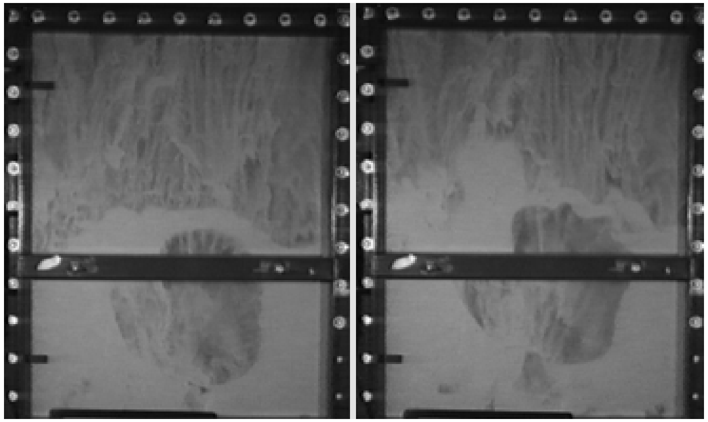


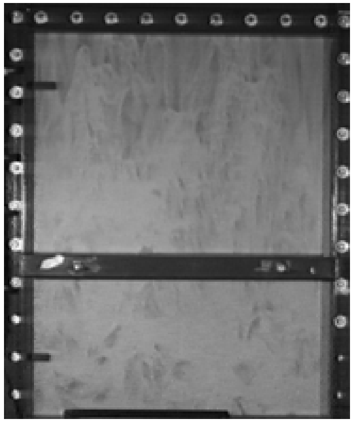


Large fluctuations in gas flow

Exploding bubble regime – in Chalmers 12 MW_{th} boiler and cold u







"Transport conditions"

Understanding bottom region conditions important for modeling of entire CFB process

For design and scale up more information is needed, especially

- Lateral distribution (in large cross sections)
  - fuel,
  - gas concentrations
  - solids flux
- Dynamics
  - Solids flow
  - Gas flow and mixing

$\Rightarrow$ Measurements under full scale conditions needed…..

"CFB Combustors" 5th framework project, 2000 – 2003

Project consortium:

Chalmers University of Technology (coordinator)

1. Technical University Hamburg-Harburg
2. Technical University of Czestochowa
3. Electrownia Turow (power plant company)
4. VSB-Technical University of Ostrava
5. Vattenfall Generation Services Thermal

5th framework project "CFB Combustors"
Measurements in Turow 235 MW_e CFB boiler

Objective

To provide data which can form a basis for modeling, reliable operation and scale-up of CFB combustors

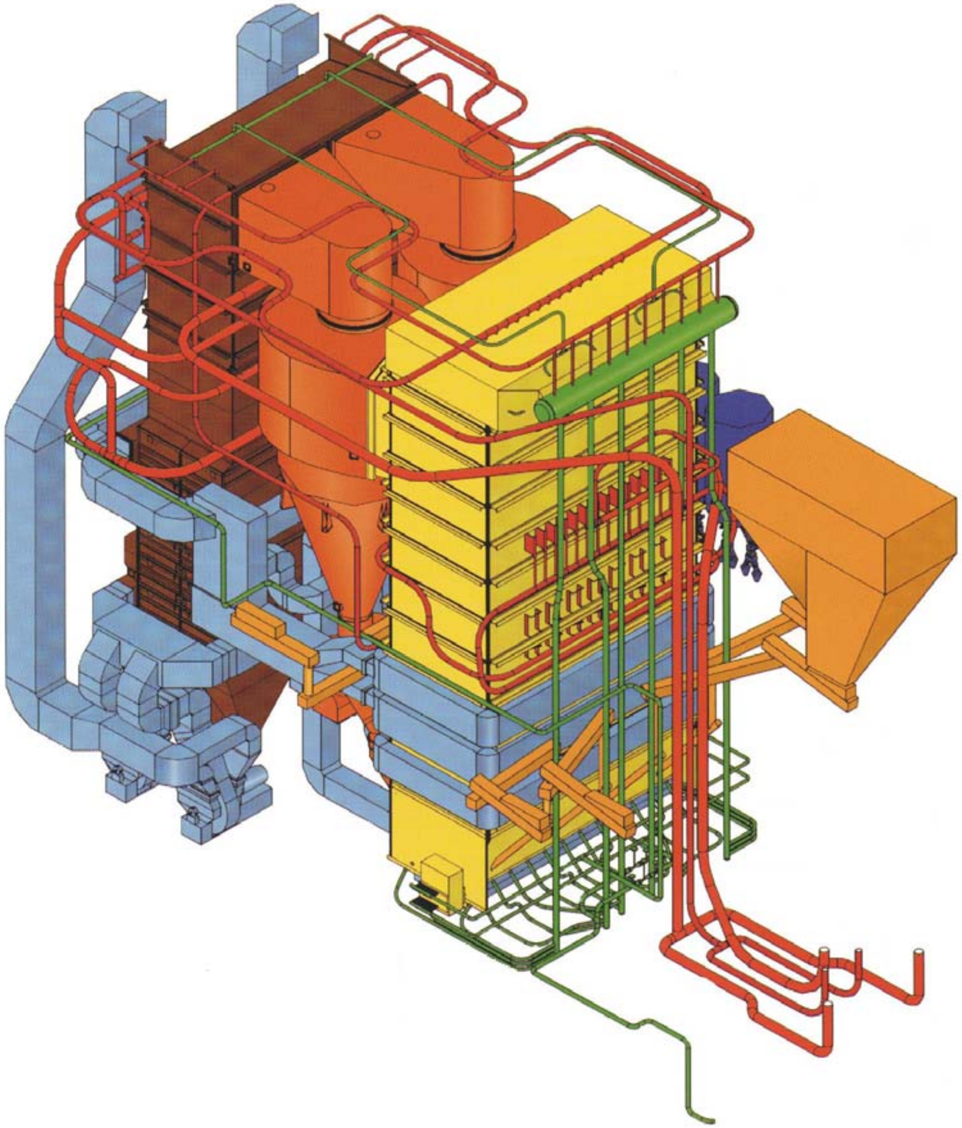
- Data on horizontal distribution over the furnace cross-section of solids size-distribution, solids flux, solids momentum, solids-volume concentration, temperature and gas concentrations
- Data on dynamic response to load changes

Examples

- Description of measurement techniques
- Bottom bed properties

Please note: work in progress

The Turow 235MW_{th} CFB Boiler



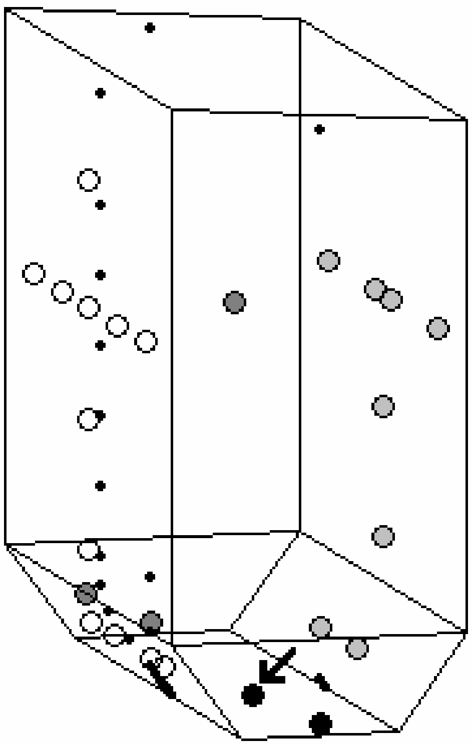
Furnace

height 42.5 m

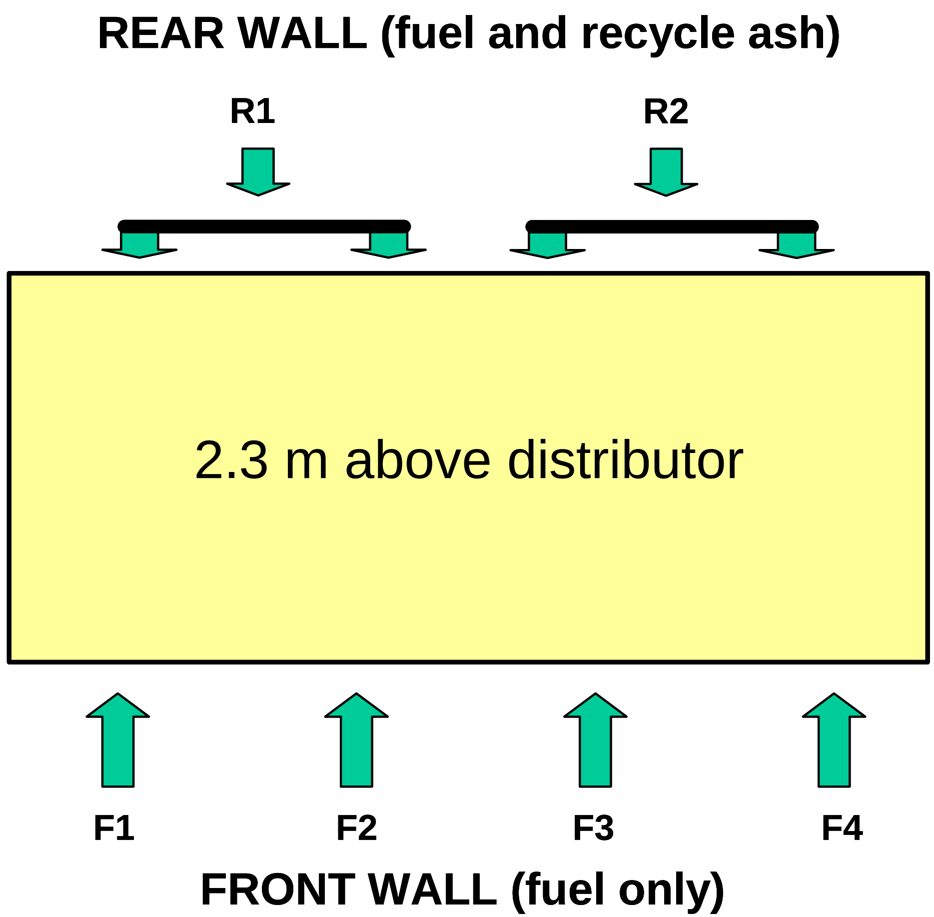
cross-section of 21.1 m x 9.9 m

25 measurement ports

25 pressure taps



Fuel feed distribution



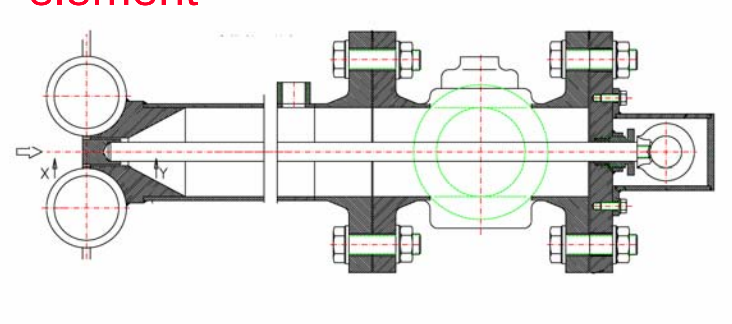
Measurement probes

- Gas suction probes
  (SO_2, NO, NO_2, CO, CO_2, O_2, CO, CH_{tot} and H_2O)
- Solids sampling probe
- Momentum probes
- Dual pressure probe
- Capacitance probe

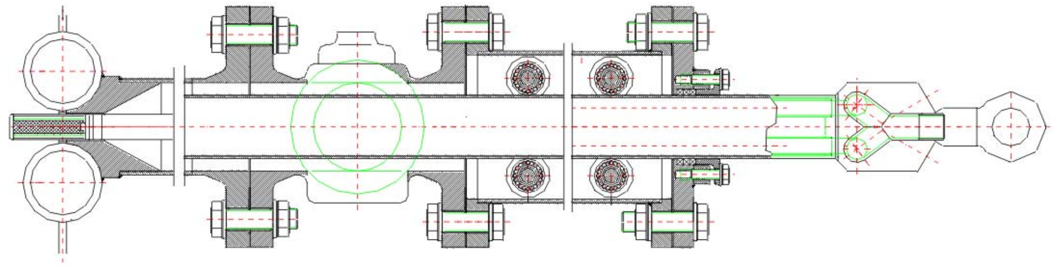
All have a rectangular cross section of 20 x 50 mm with lengths of 3.7 m (4.5 m momentum probe) and 2.7 m

Ports and probes

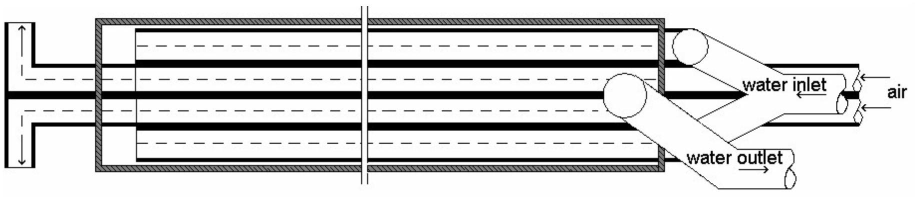
Hole in the membrane tube-wall
and
port equipped with insertion element



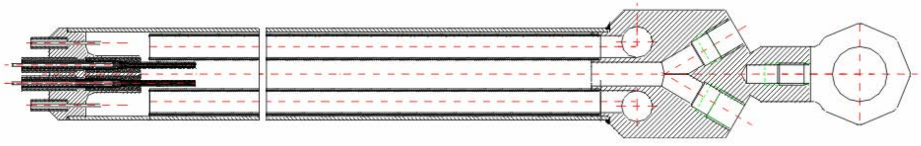
A port equipped with high-precision guidance and with a gas suction probe inserted



The solids momentum probe



Needle-type capacitance probe



Capacitance probe (TUHH)

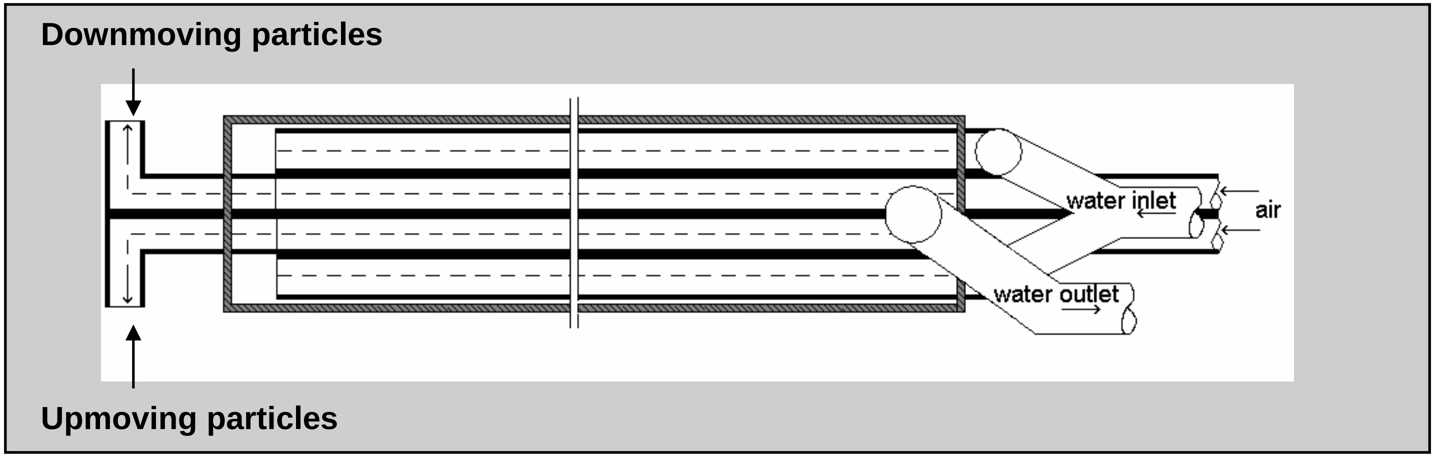
Momentum probe

- **Measures differential pressure, Δp_m, between upward and downward pointing pressure taps (down- and upmoving particles respectively). Δp_m also called impact pressure.**

- $$\Delta p_m = \alpha G_s U_p + k = \frac{\alpha G_s^2}{\rho_s c_s} + k \quad \left(\frac{N}{m^2}, \frac{kg}{ms^2}\right)$$ **and** $$U_p = \frac{G_s}{\rho_p c_s}$$

  where α and k are constants

- **Dynamics and statistics of local solids flux in vertical direction**

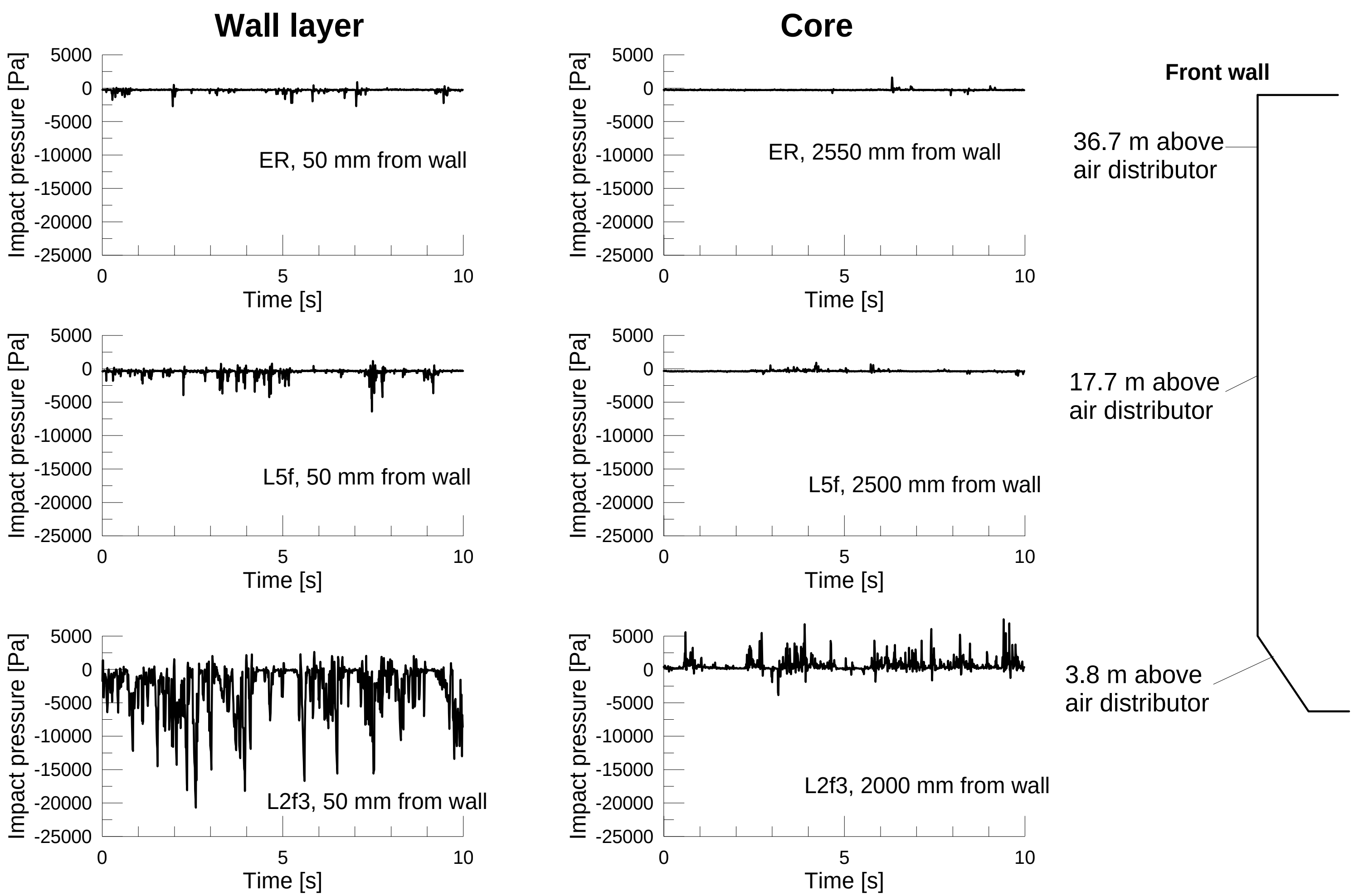


Solids momentum probe for dynamics of solids flux

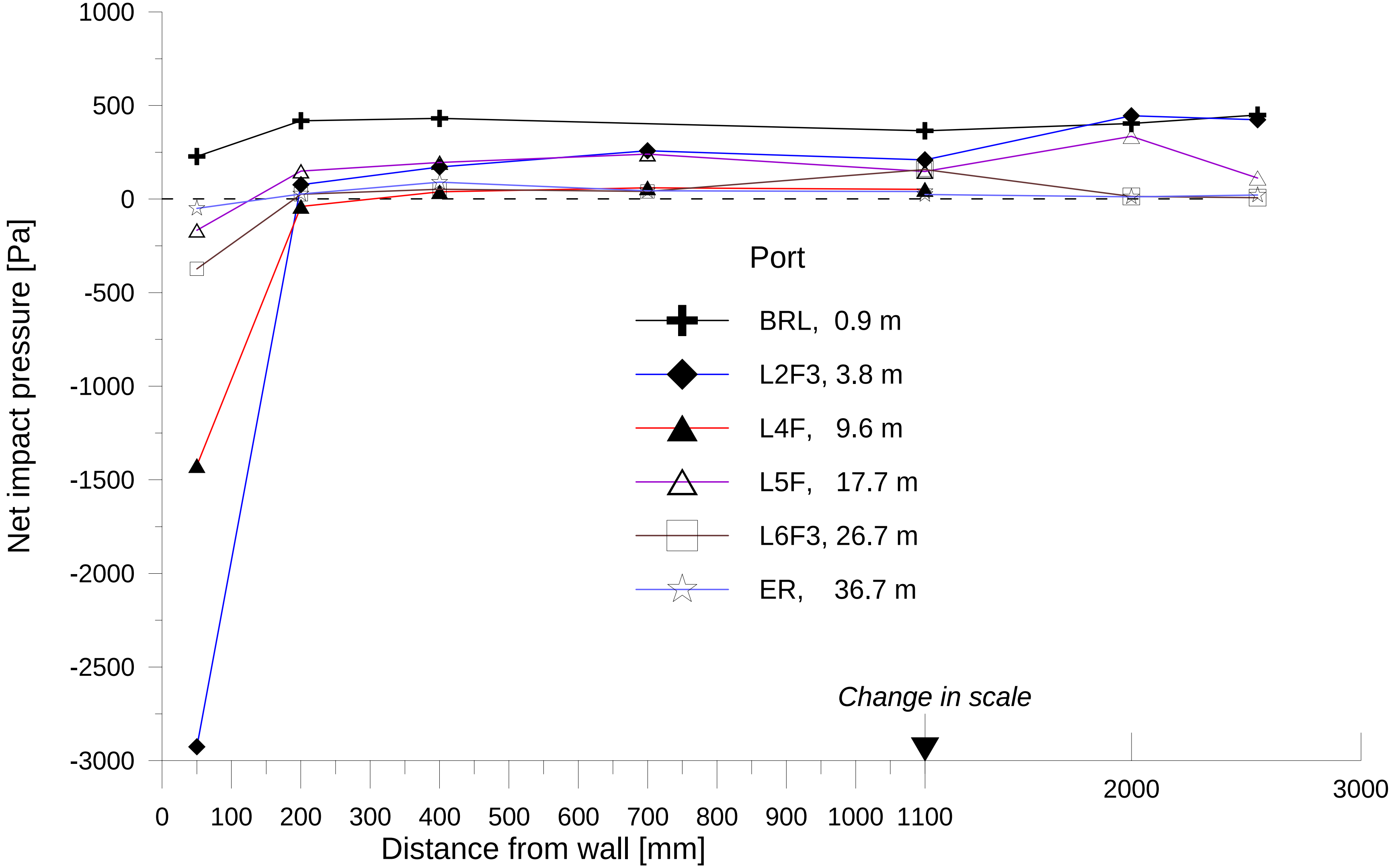
Dual pressure probe for solids velocity measurements

Example of results
(- dynamics of solids flow)
- bottom region characteristics

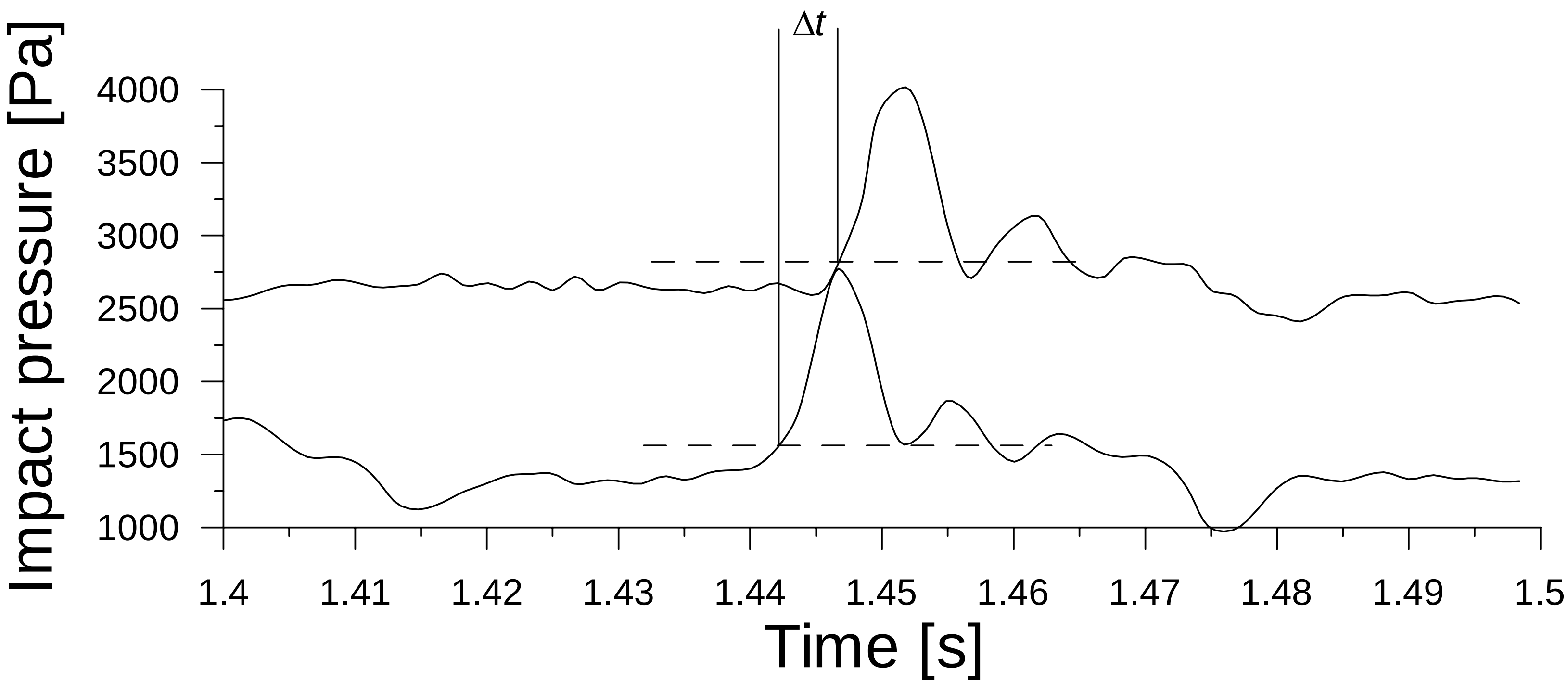
Momentum flux in furnace



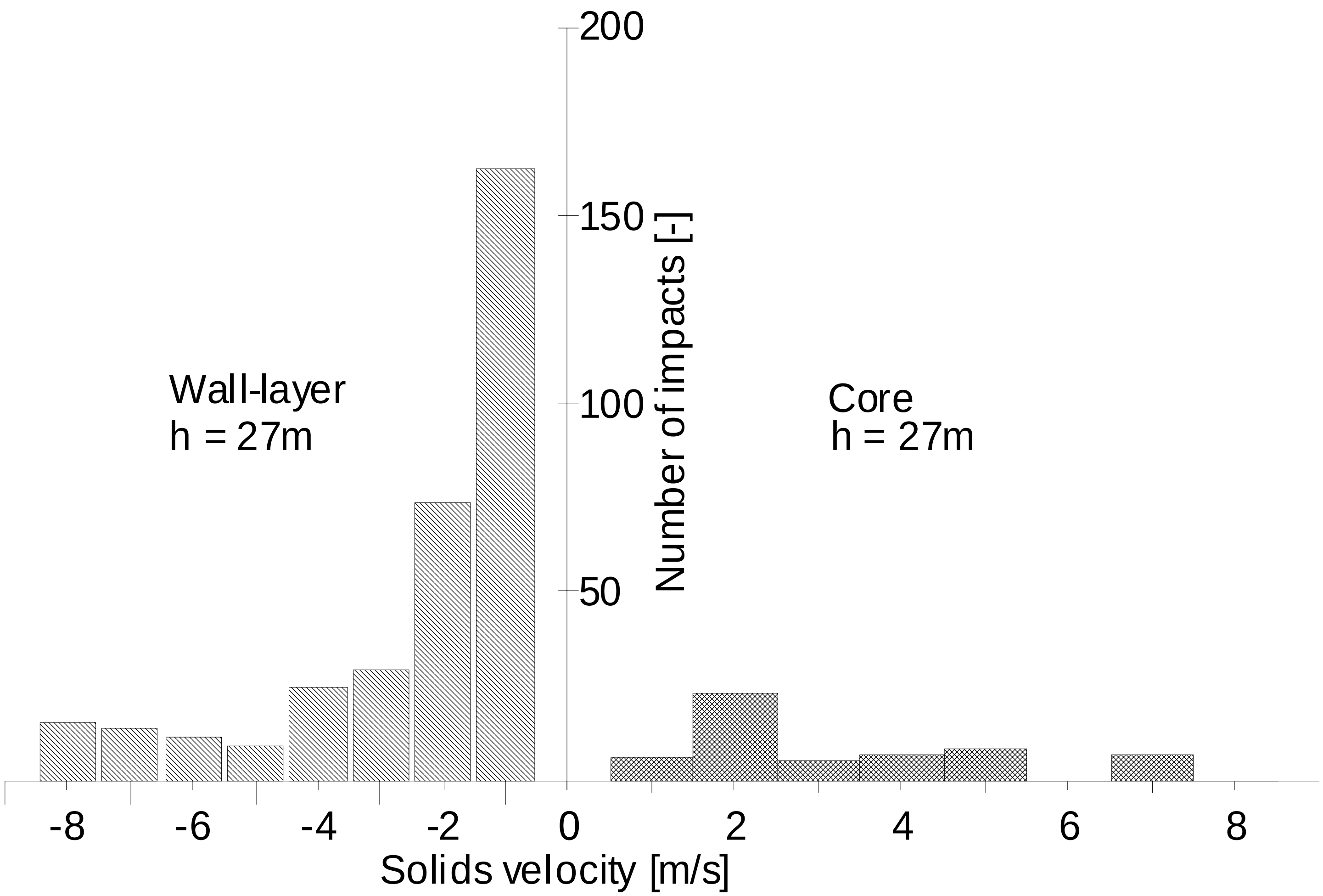
Vertical changes in profiles of net impact pressure



Solids velocity from dual pressure probe

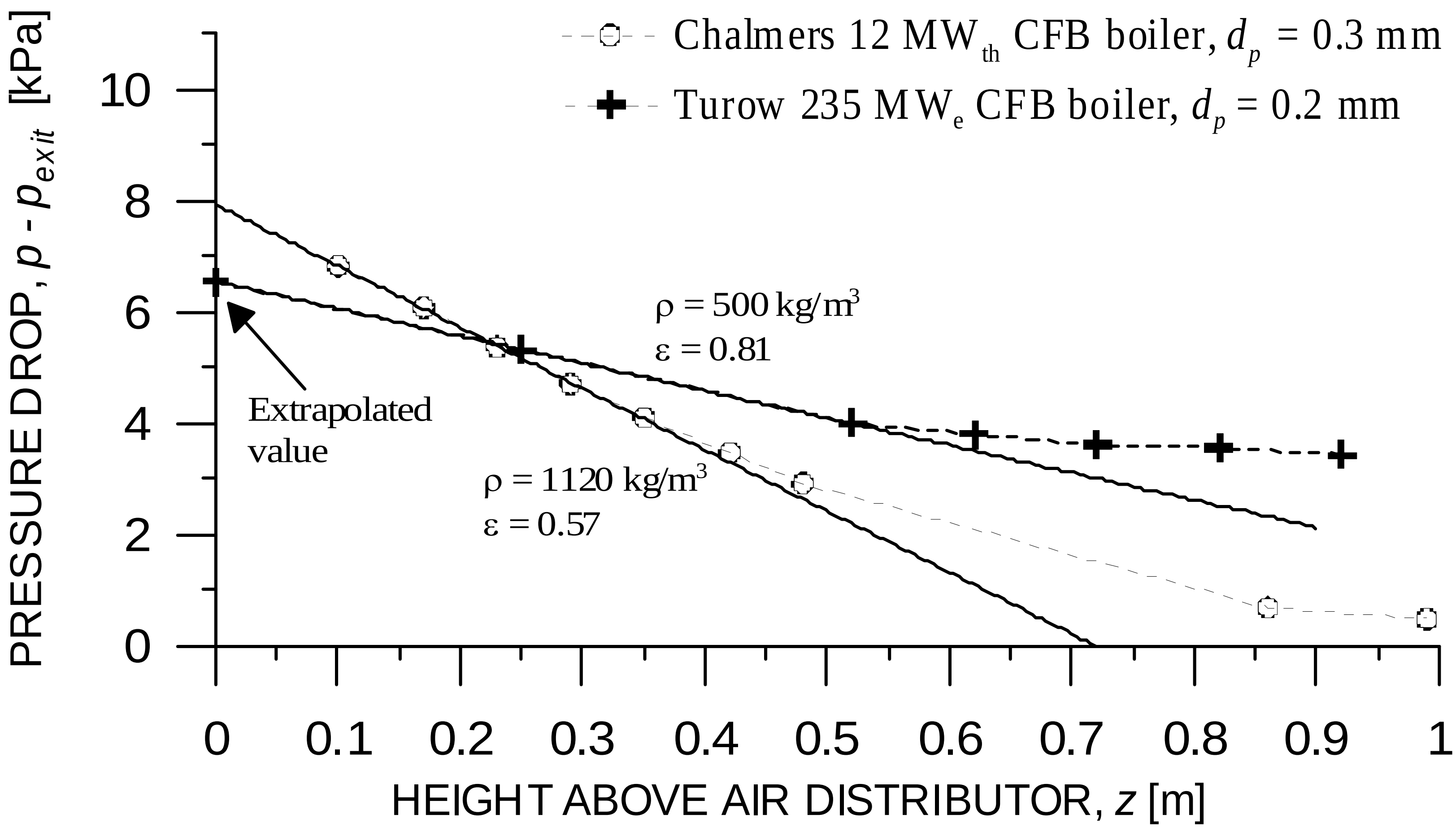


Solids velocity from dual pressure probe

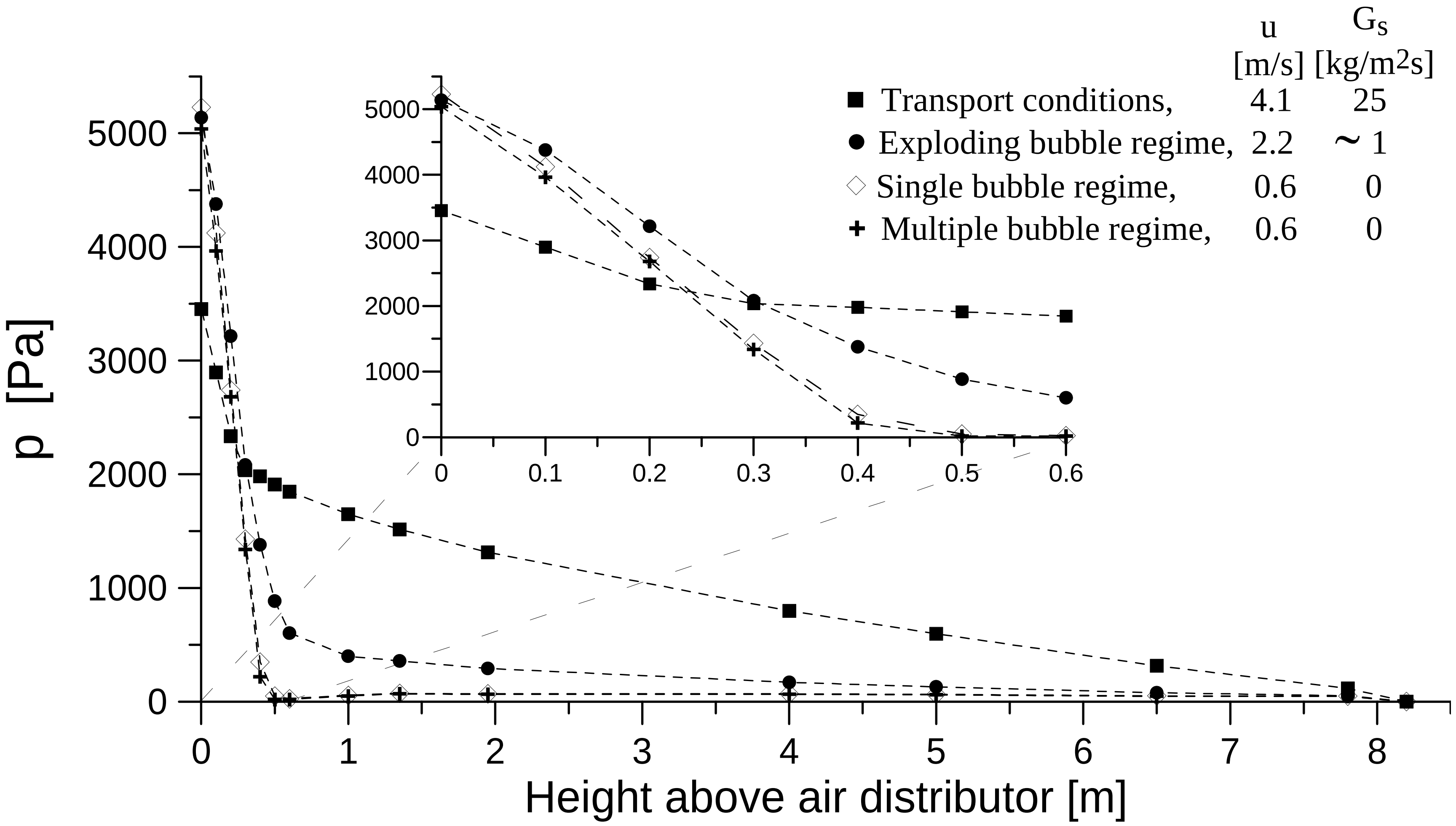


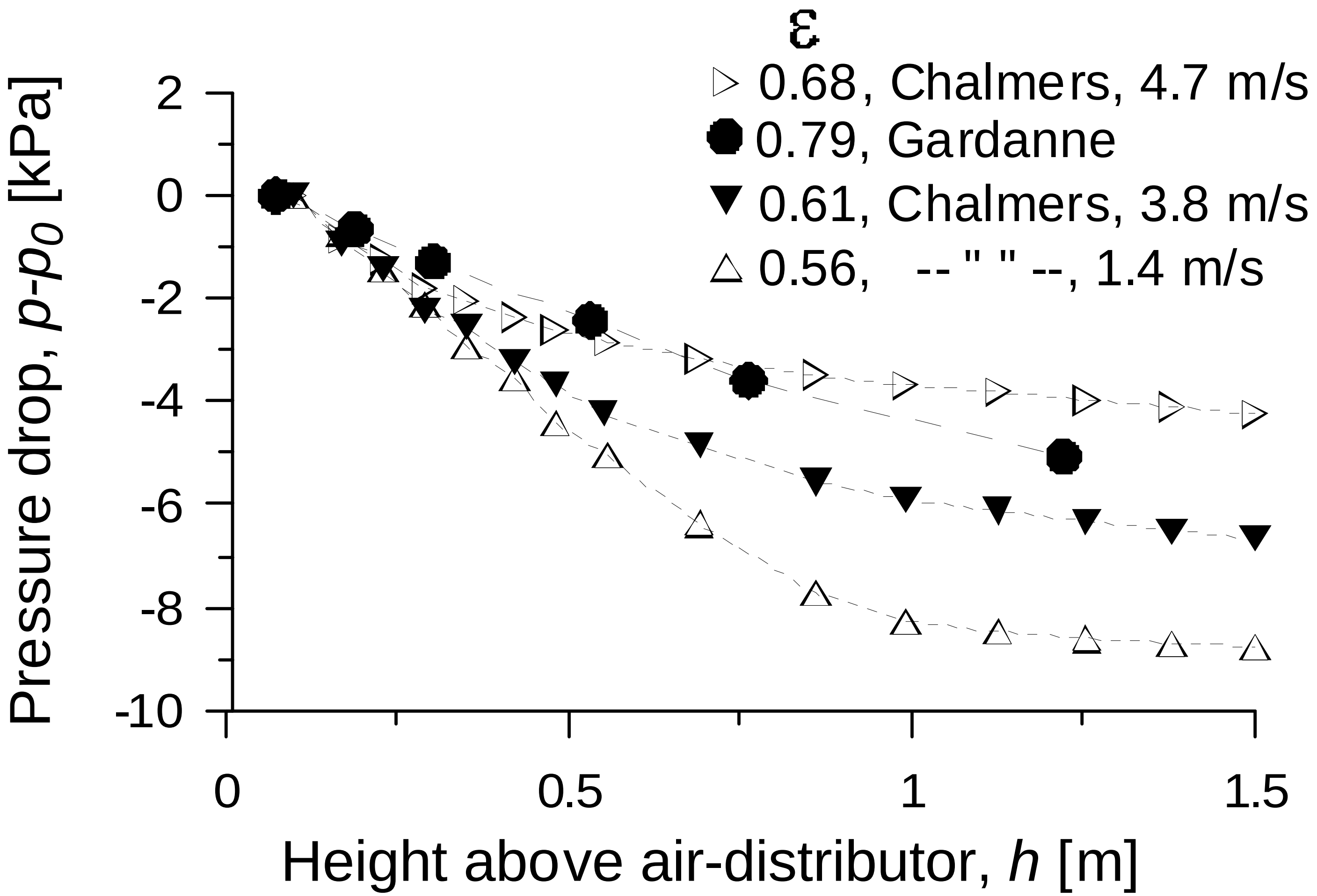
To detect bottom region conditions: pressure taps and/or measurement ports in lower region of furnace

Boiler	No. of pressure taps*	No. of meas. ports	Vertical positions of the lowest pressure taps [m]	Vertical positions of the lowest meas. port [m]
Chalmers	32	36	0.1-0.17	0.26
Chatham	-	2	-	5.1
Flensburg	8	2	0.2-3.7	17.3
Örebro	-	5	-	18.5
Duisburg	10	5	0.2-2.0	8.6
E. Huchet	12	1	1.0-1.5	13.8
Gardanne	7	2	0.03-0.20	~1
Turow	25	25	0.25-0.52	0.8


Chalmers 12 MWth CFB boiler, dp = 0.3 mm
Turow 235 MWe CFB boiler, dp = 0.2 mm
ρ = 500 kg/m3
ε = 0.81
ρ = 1120 kg/m3
ε = 0.57
Extrapolated value
PRESSURE DROP, p - pexit [kPa]
HEIGHT ABOVE AIR DISTRIBUTOR, z [m]
0
2
4
6
8
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

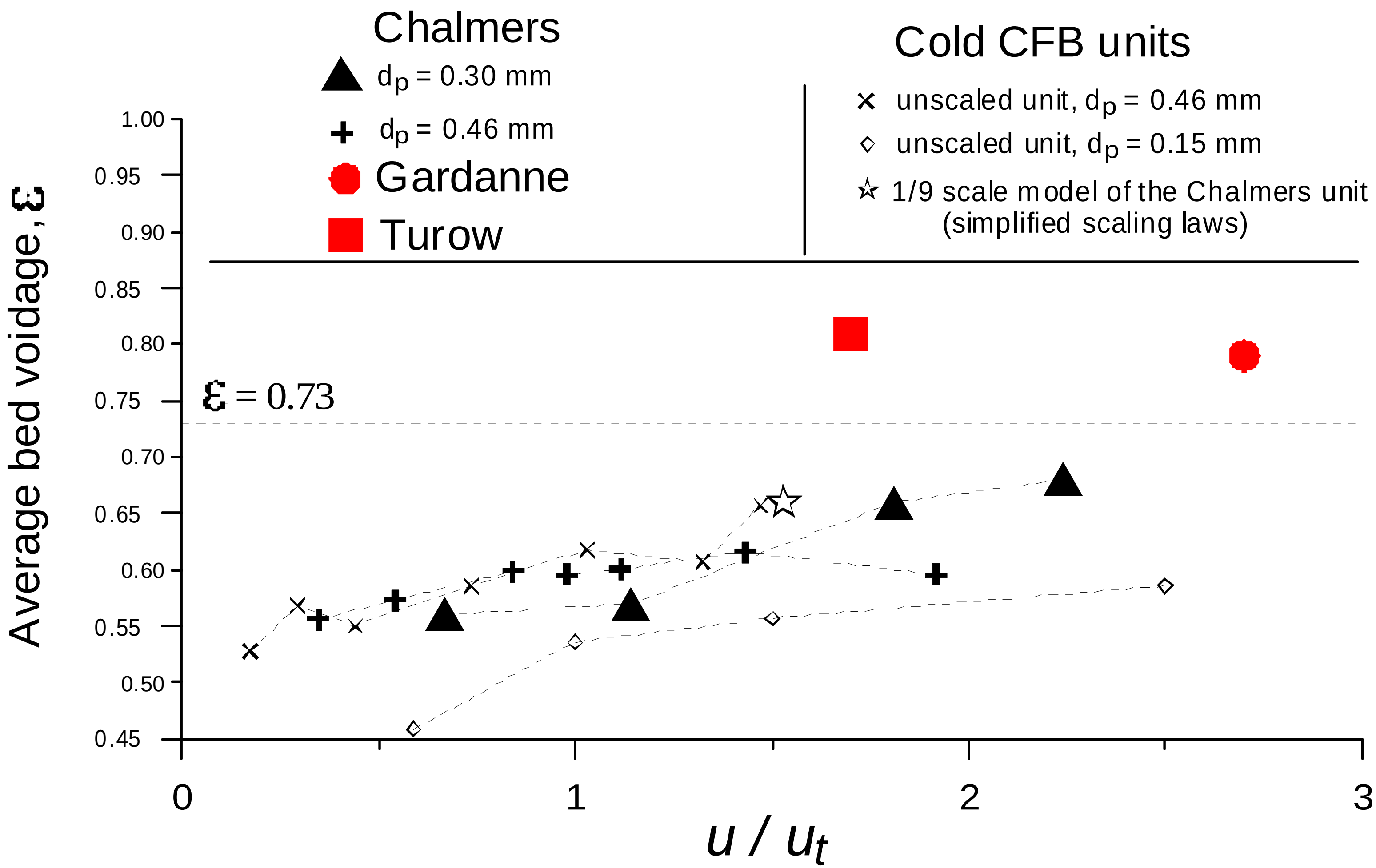
Regimes found in a 0.7x0.12x8.5 m riser




ε
0.68, Chalmers, 4.7 m/s
0.79, Gardanne
0.61, Chalmers, 3.8 m/s
0.56, -- " " --, 1.4 m/s
Pressure drop, p-p0 [kPa]
2
0
-2
-4
-6
-8
-10
0
0.5
1
1.5
Height above air-distributor, h [m]

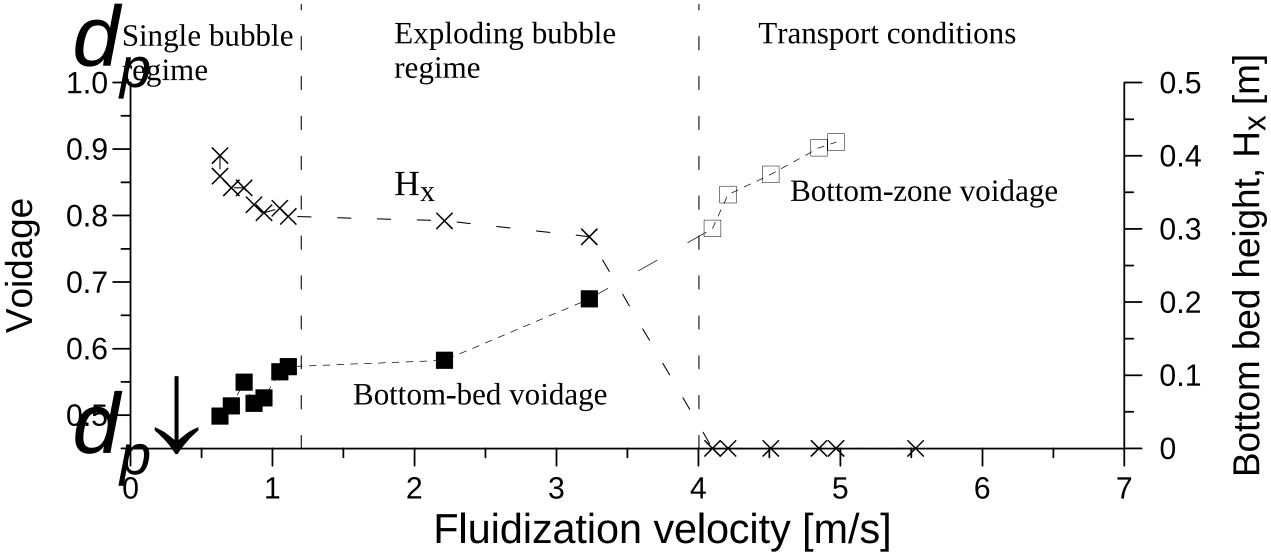
Bottom bed voidage

(Only conditions with presence of bottom bed shown for Chalmers boiler and cold units)



Operation with no bottom bed – “transport conditions”

$u_0 \, , \;\; \Delta P_0 \, , \, d_p \;\rightarrow\;\; u\uparrow , \, \Delta P_0 \, ,$



d_p

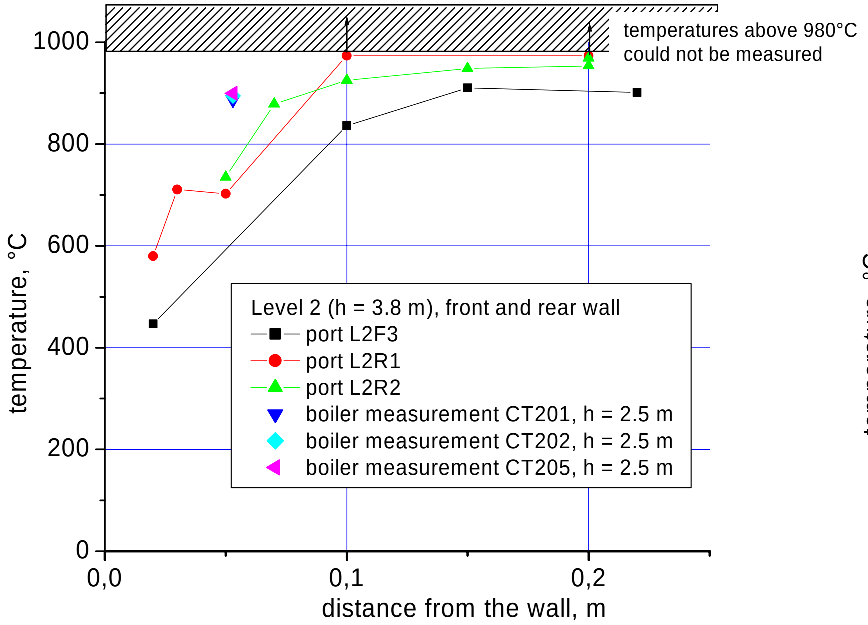
$d_p\downarrow$

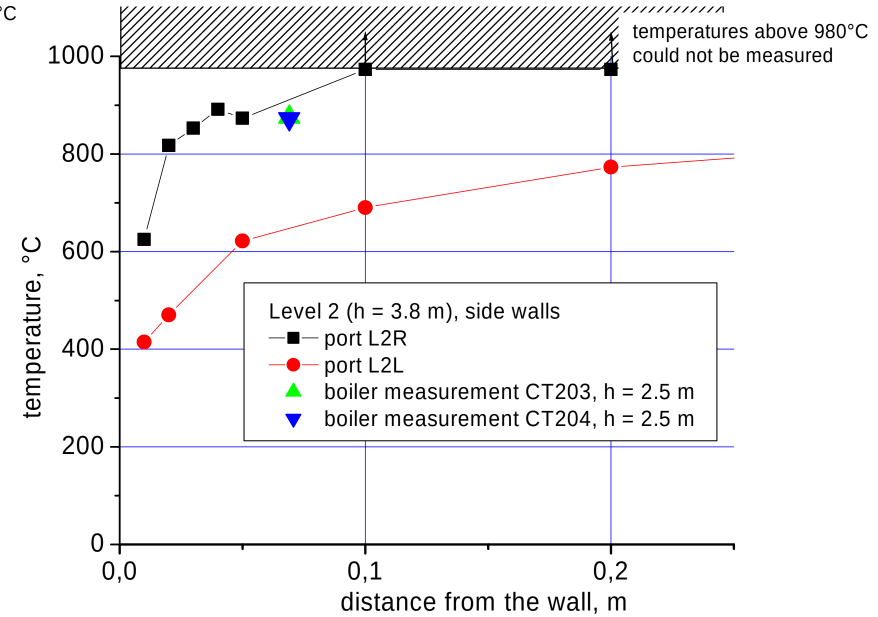
$u_0 \, , \;\; \Delta P\downarrow , \, d_p$

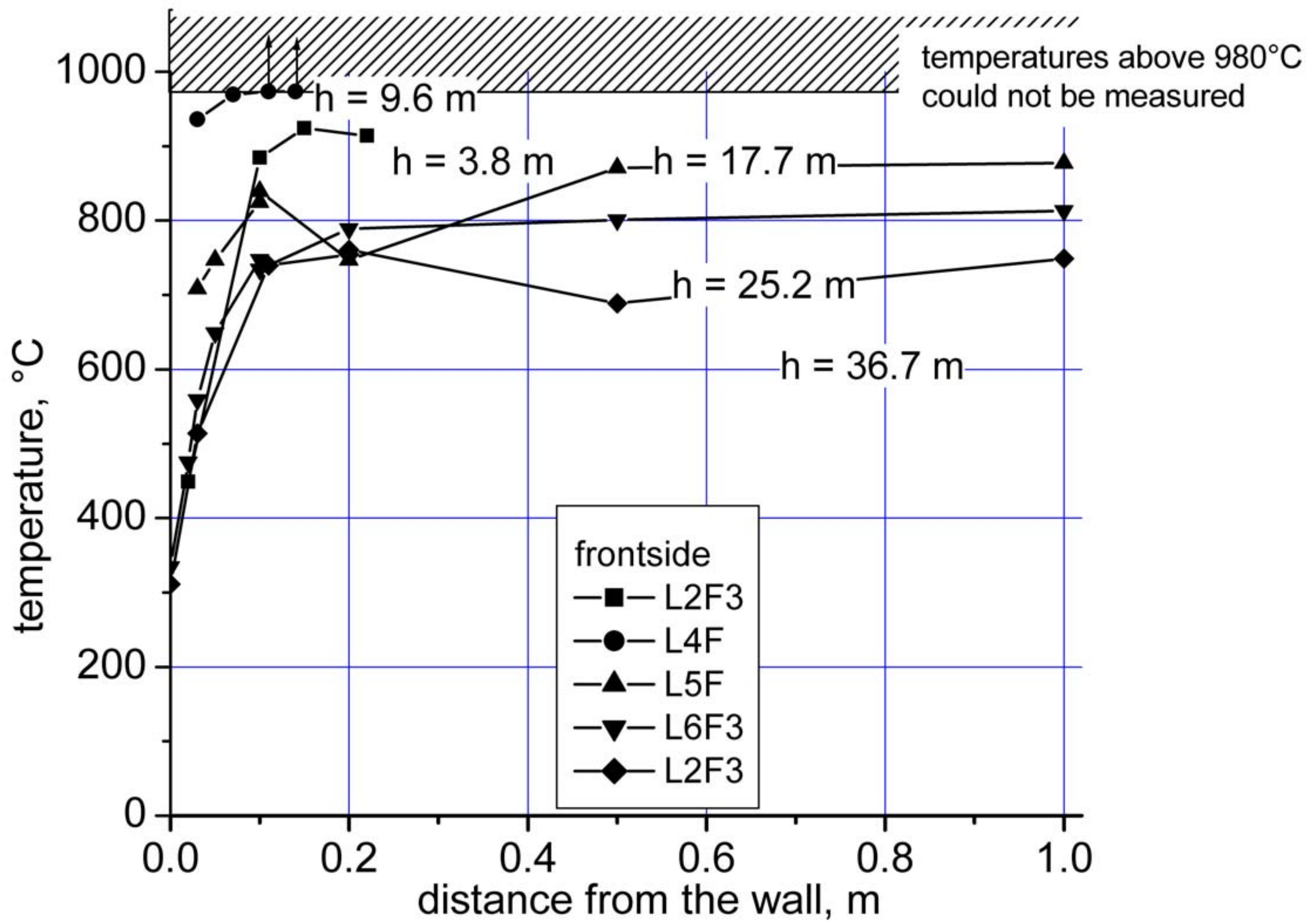
$u_0 \, , \;\; \Delta P_0 \, ,$

Cold unit data (0.7 x 0. 12 x 8.5 m CFB riser)

Temperature > 980 ºC at several locations






temperatures above 980°C
could not be measured
h = 9.6 m
h = 3.8 m
h = 17.7 m
h = 25.2 m
h = 36.7 m
frontside
L2F3
L4F
L5F
L6F3
L2F3
1000
800
600
400
200
0
0.0
0.2
0.4
0.6
0.8
1.0
temperature, °C
distance from the wall, m

Conclusions

- In-situ measurement techniques were successfully applied to study in-furnace processes in the 235 MW_e Circulating Fluidized Bed boiler
- Results illustrate the complex dynamics of the in-furnace flow and mixing with pronounced lateral variations in gas concentrations over the furnace cross section. In particular:
  - strong downflow of solids near the wall
  - temperatures at the wall (< 0. 1 m) are much lower than temperatures inside the boiler
  - **average solids concentration in bottom region lower than what correspond to previously observed observations**
  - **high temperatures observed – related to low solids inventory?**
  - **boiler temperatures for control purposes are measured within wall layer/zone**
  - oxygen-depleted wall region with thickness of 0.5 m
  - differences in O_2 between front and rear wall indicate that lateral ash flow brings fuel deeper into the combustion chamber and thus helps to avoid the formation of plumes

Acknowledgements

- Turow – highly professional planning of measurement program. Experiments started same day as planned, in spite of planning phase of one year
- European commission