Vertical distribution of solids in a furnace of a 670 MW_{th} CFB boiler

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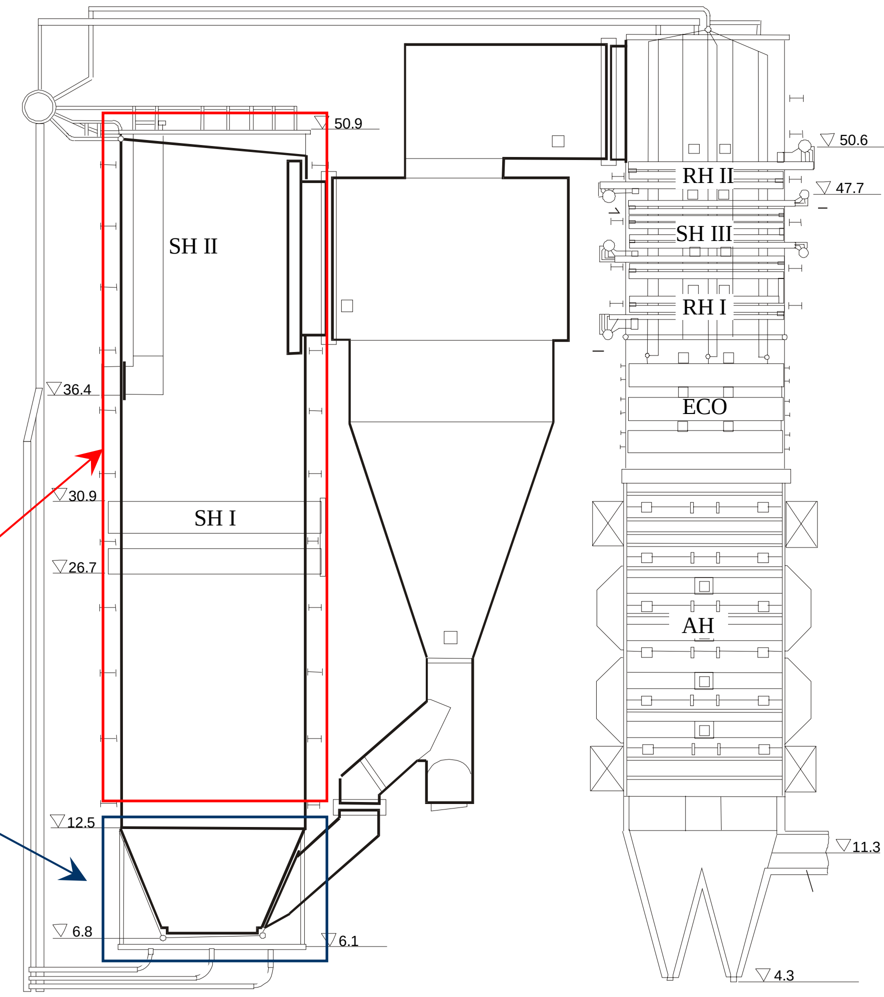
This work was financed in part by the European Commission
within the 5 Framework programme

PROCESSES IN LARGE-SCALE CIRCULATING FLUIDIZED BED COMBUSTORS

CONTRACT ENK5-1999-00005

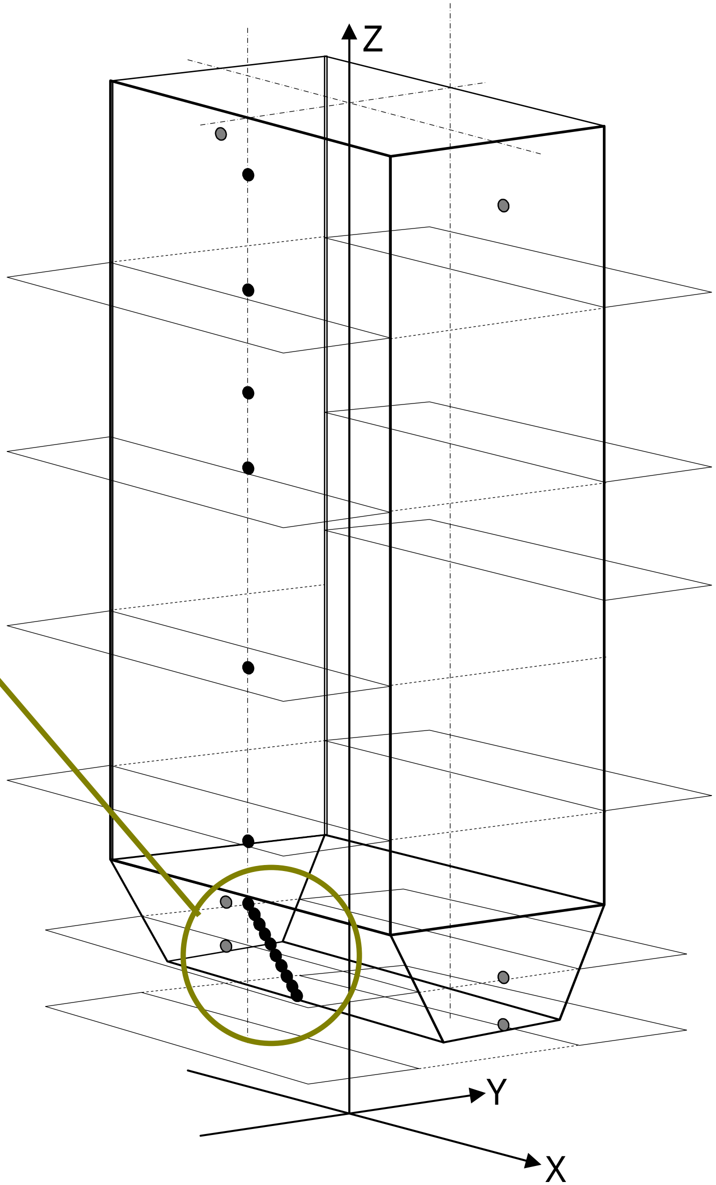
670 MW_{th} CFB BOILER

Steam flow	- 185,4 kg/s
Steam pressure	- 13,17 MPa
Steam temperature	- 540 °C
Fuel	- Lignite
HHV	- 8,37 - 12,14 MJ/kg
Height of the furnace	- 44,8 m
Cross – section of the upper part of the furnace	- 21,2 m x 9,9 m
Cross – section of the bottom part of the furnace	- 21,2 m x 5,2 m
Height of the bottom part of the furnace	- 6,7 m



Technical data and design parameters

MEASUREMENT LOCATION



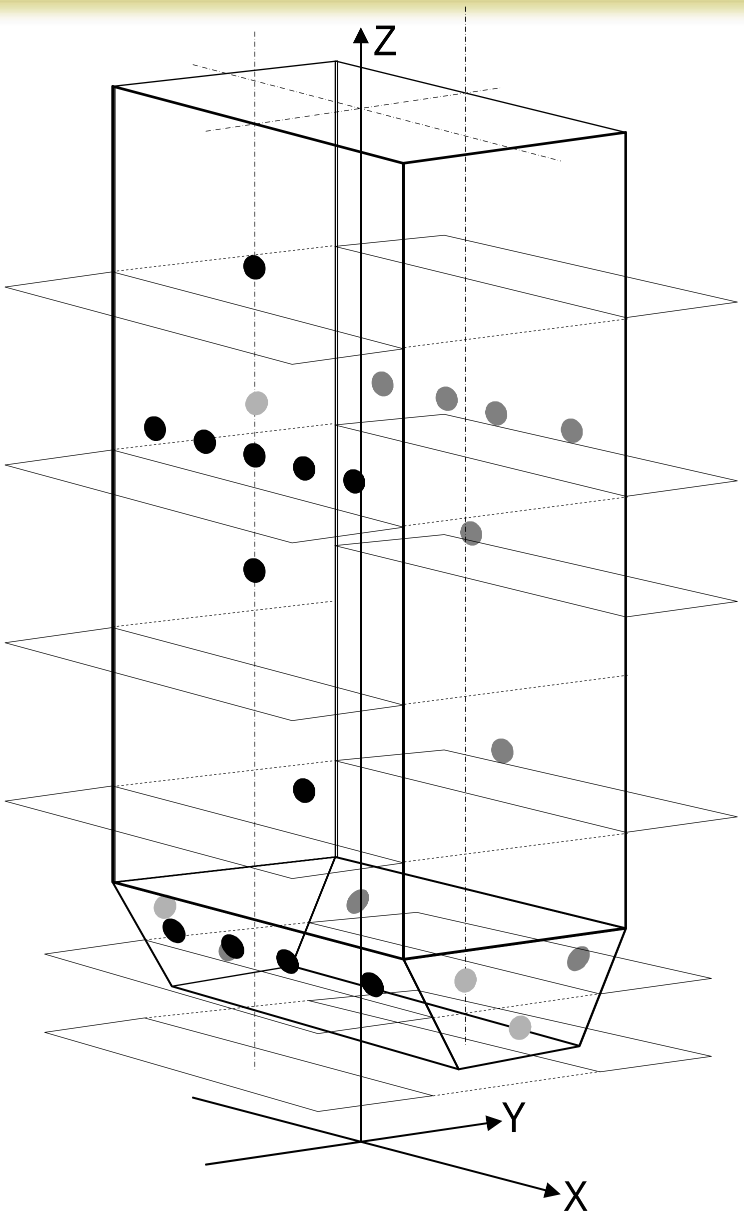
18 measurement holes
on the fins of the membrane tube walls
of on the front side of the furnace

6 pressure taps on the side walls

3 pressure taps in the wind box

Pressure measurement

MEASUREMENT LOCATION

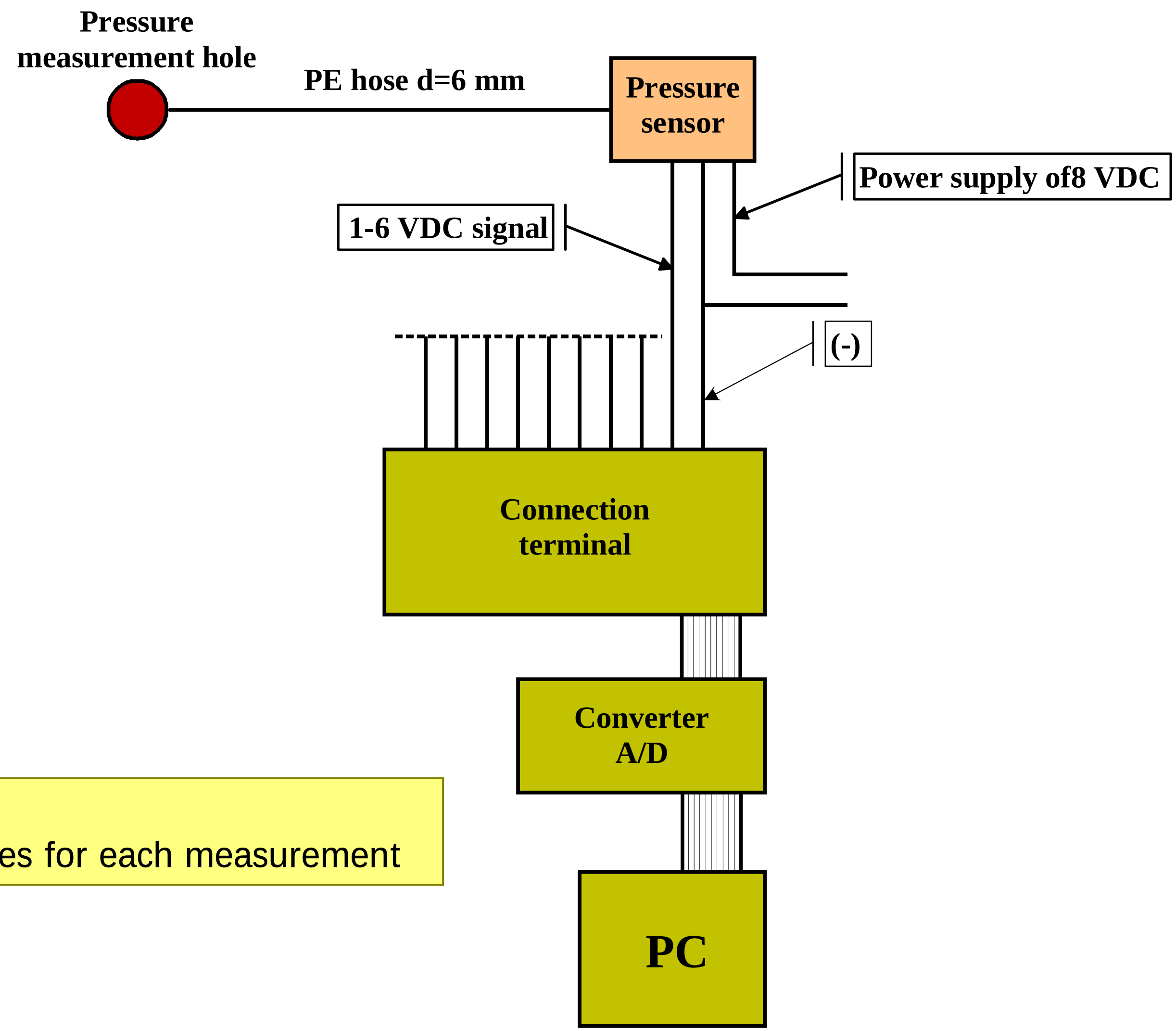


25 measurement holes on the fins of the membrane tube walls of the furnace

The holes – a rectangular shape, 52 mm x 22 mm

Solids sampling

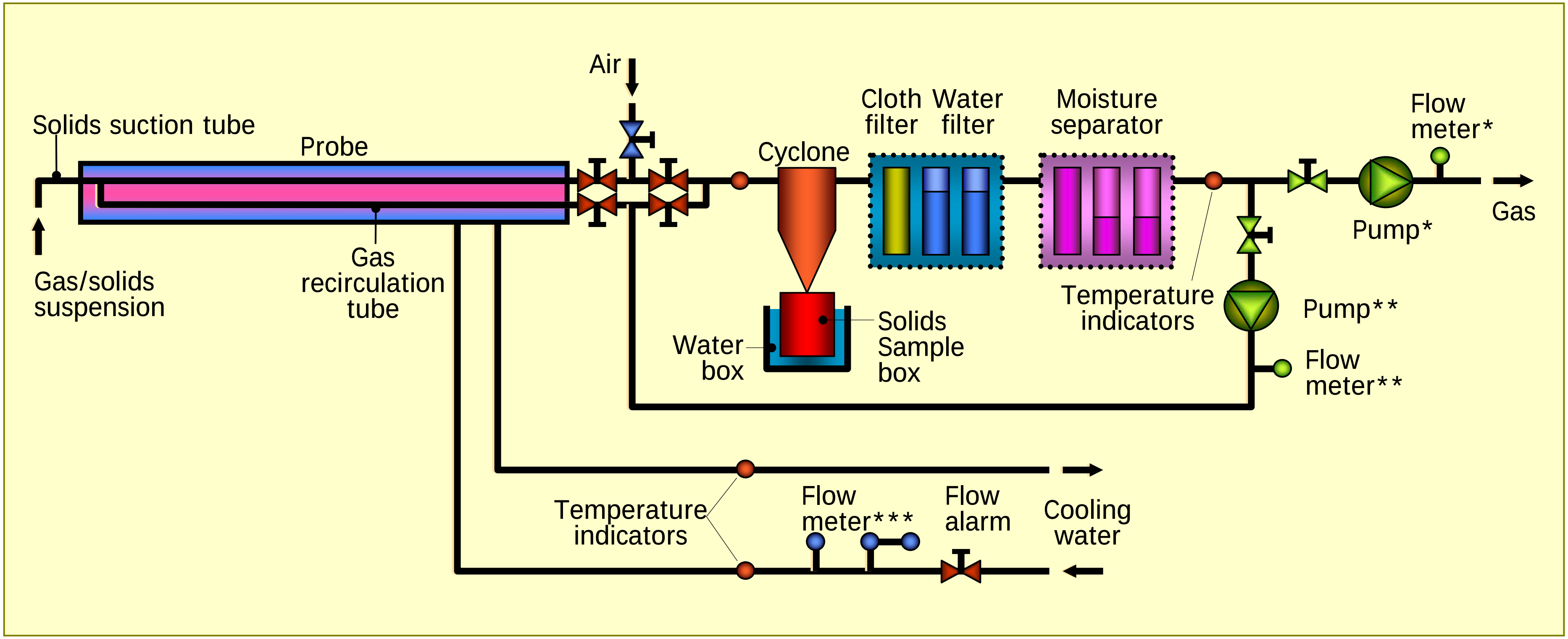
EQUIPMENT



Sampling frequency - 200 Hz
Total sampling time - 10 minutes for each measurement

Diagram of the pressure measurement system

EQUIPMENT



Pump* : Dry rotary pump, four bucket; induction motor: 220V / 50Hz / 0,55kW; Q=12m^3/h; p=30kPa; T=100^{O}C

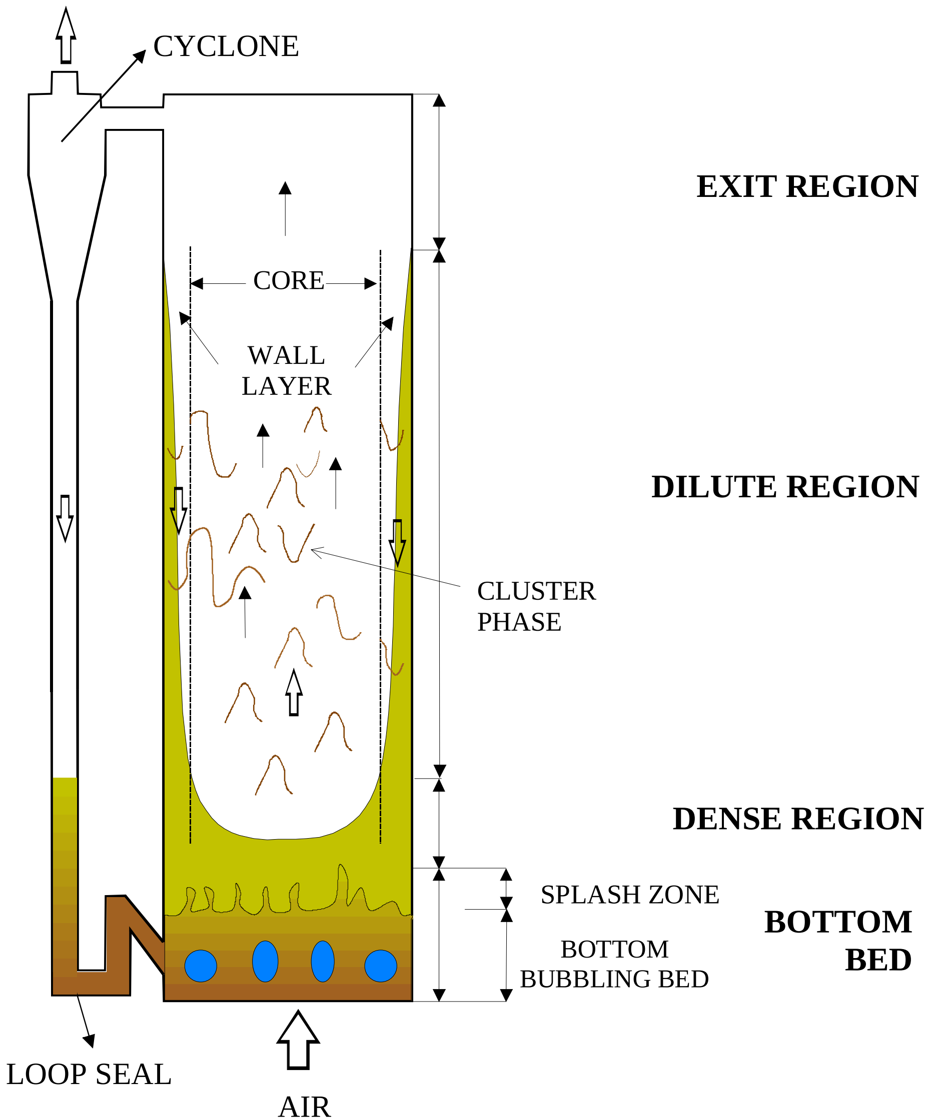
Pump**: Dry rotary pump, four bucket; induction motor: 220V / 50Hz / 0,55kW; Q=12m^3/h; p=30kPa; T=100^{O}C

Flow meter*: 0,0 – 1,5 m^3/h · Flow meter**: 0,0 – 4,0 m^3/h · Flow meter***: 0,0 – 200 kg/h

DISTANCE FROM THE WALL: 0,05 m; 0,1 m; 0,2 m; 0,4 m; 0,7 m; 1,0 m

Solids sampling

Illustration of a typical flow structure in circulating fluidized bed [14]



$0.15 > c_d \geq 0.5$

$0.05 > c_g \geq 0.15$

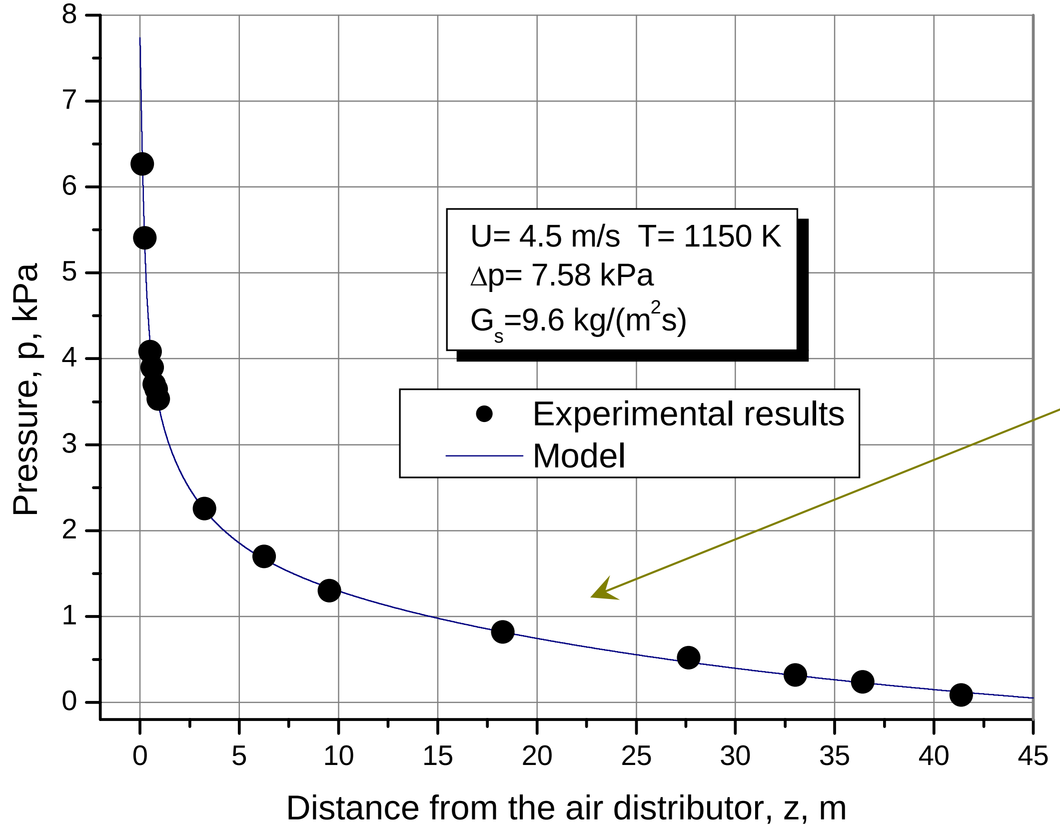
$0.01 > c_r \geq 0.05$

$c_w \leq 0.01$

→ [1]

PRESSURE MEASUREMENTS

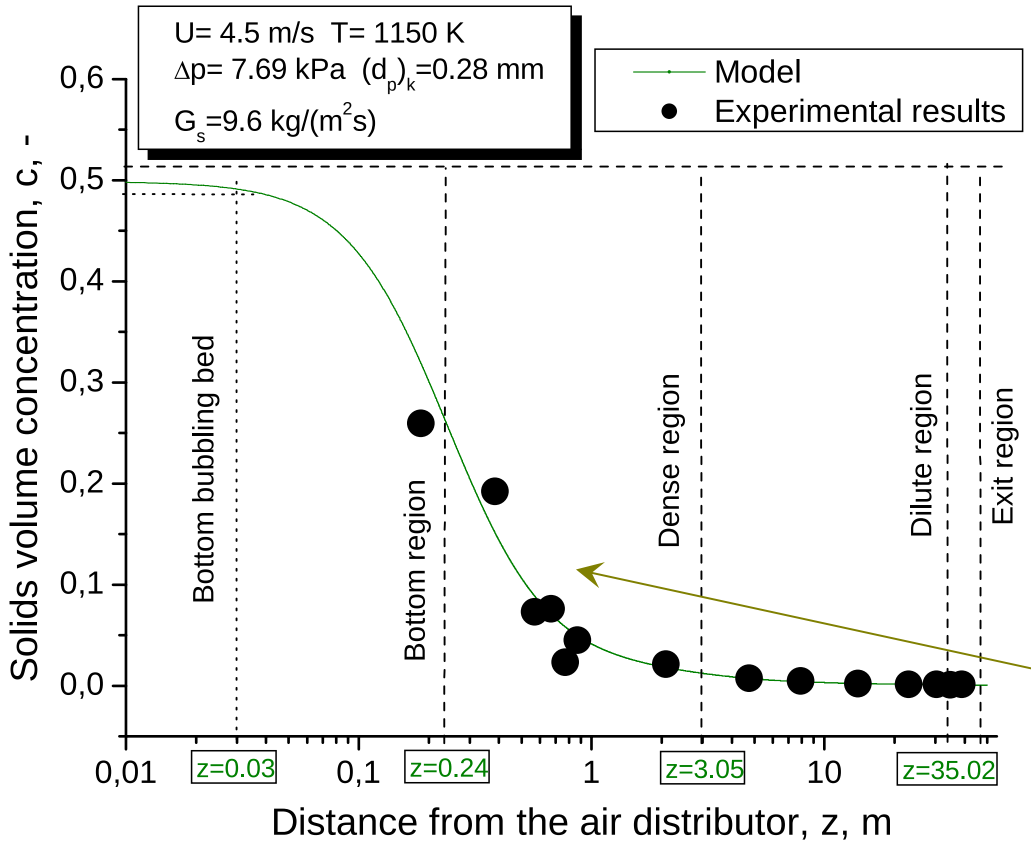
$$p(z) = p_0 - A_d \cdot z_d \cdot arctg\left(\frac{z}{z_d}\right) - A_g \cdot z_g \cdot arctg\left(\frac{z}{z_g}\right) - A_r \cdot z_r \cdot arctg\left(\frac{z}{z_r}\right) - A_w \cdot z_w \cdot arctg\left(\frac{z}{z_w}\right)$$



p_0= 7.74 kPa
p_{d0}= 4.62 kPa
p_{g0}= 1.74 kPa
p_{r0}= 1.11 kPa
p_{w0}= 0.27 kPa
A_d= 12.30 kPa/m
A_g= 0.38 kPa/m
A_r= 0.035 kPa/m
A_w= 0.006 kPa/m
z_d= 0.24 m
z_g= 3.05 m
z_r= 35.02 m
z_w= 44.80 m
R^2 = 0.9995

Pressure profile as function of distance from air distributor

PRESSURE MEASUREMENTS



$$c(z) = -\frac{1}{\rho_s \cdot g} \cdot \frac{dp}{dz}$$

$$\frac{dp}{dz} = -\left[\frac{A_d}{1+\left(\frac{z}{z_d}\right)^2} + \frac{A_g}{1+\left(\frac{z}{z_g}\right)^2} + \frac{A_r}{1+\left(\frac{z}{z_r}\right)^2} + \frac{A_w}{1+\left(\frac{z}{z_w}\right)^2}\right]$$

$\bar{c}_d = 0,38$

[1] $0,4 - 0,2$

$\bar{c}_g = 0,14$

[1] $0,05 - 0,14$

$\bar{c}_r = 0,007$

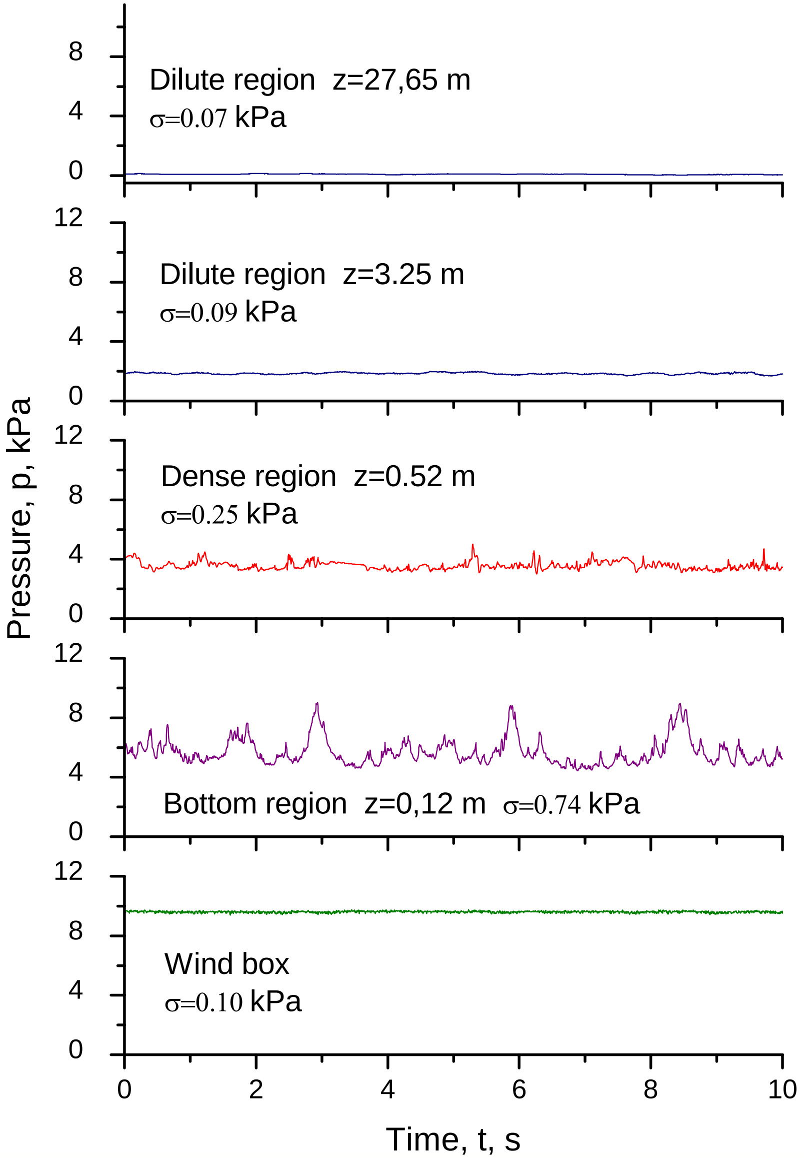
[1] $0,01 - 0,05$

$\bar{c}_w = 0,001$

[1] $< 0,01$

Solids volume concentration as function of distance from air distributor

PRESSURE MEASUREMENTS



U=4.5 m/s

T=1150 K

Δp=7.58 kPa

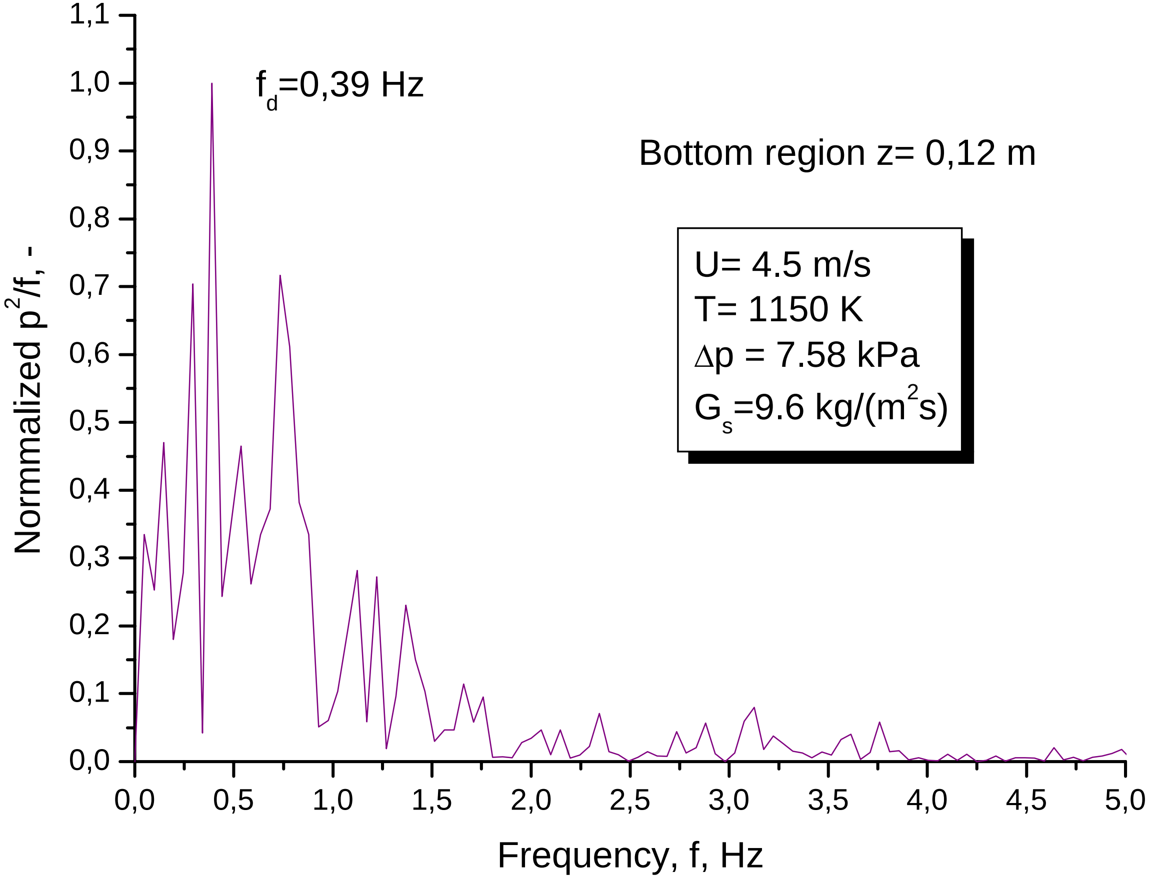
G_s=9.6 kg/(m^{2}s)

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{n=1}^{N}(p(n)-\overline{p})^2}$$

$$G_s = c_w \cdot \rho_s \cdot (U - U_t)$$

Pressure distribution as a function of time

PRESSURE MEASUREMENTS



$H / D_e = 41 \quad f^d = 1\ Hz$ [2,3]

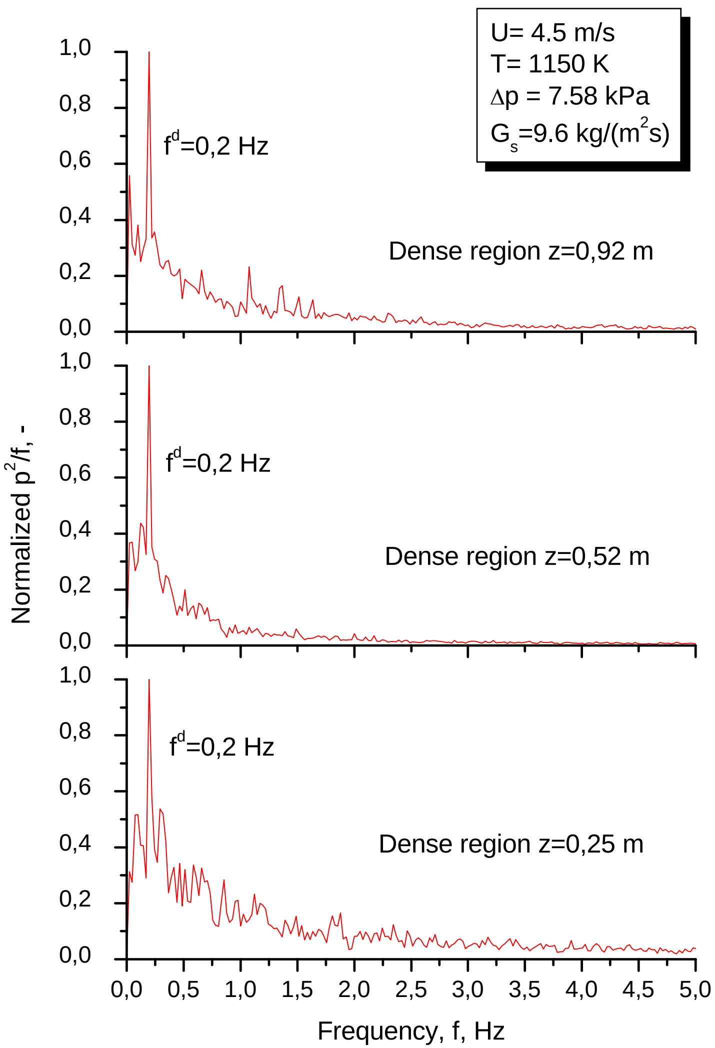
$H / D_e = 37 \quad f^d = 0,7\ Hz$ [4]

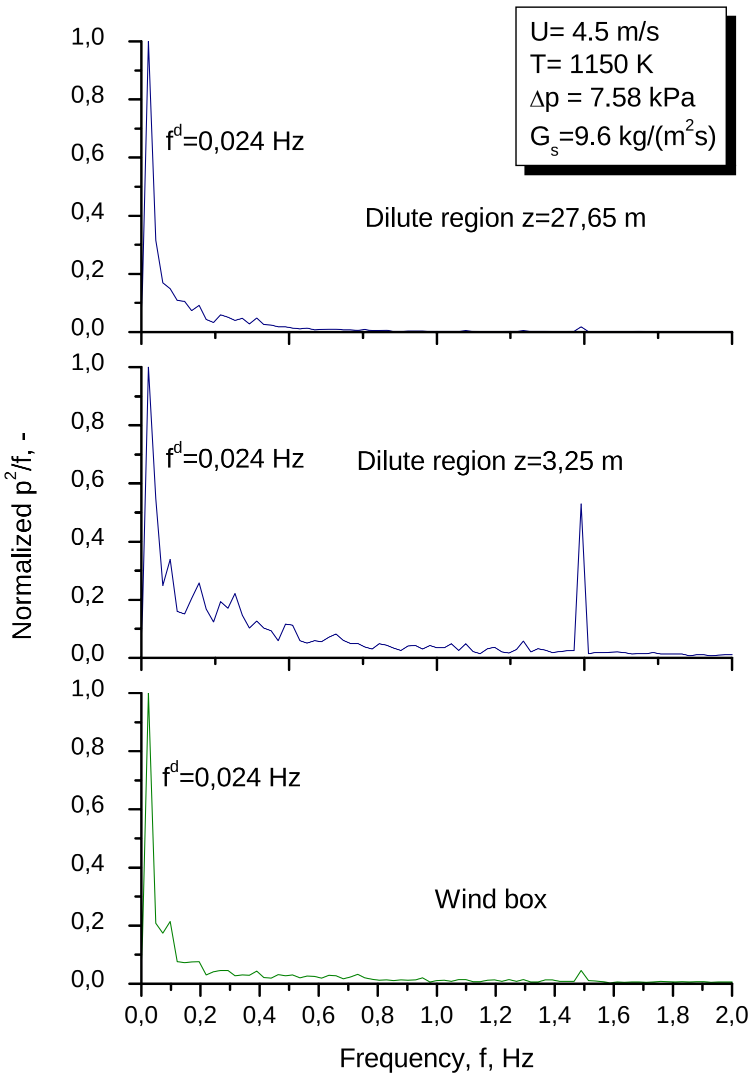
$H / D_e = 8,8 \quad f^d = 0,5\ Hz$ [2,3]

$H / D_e = 7 \quad f^d = 0,4\ Hz$ [4]

Power spectral density of pressure - bottom region of furnace

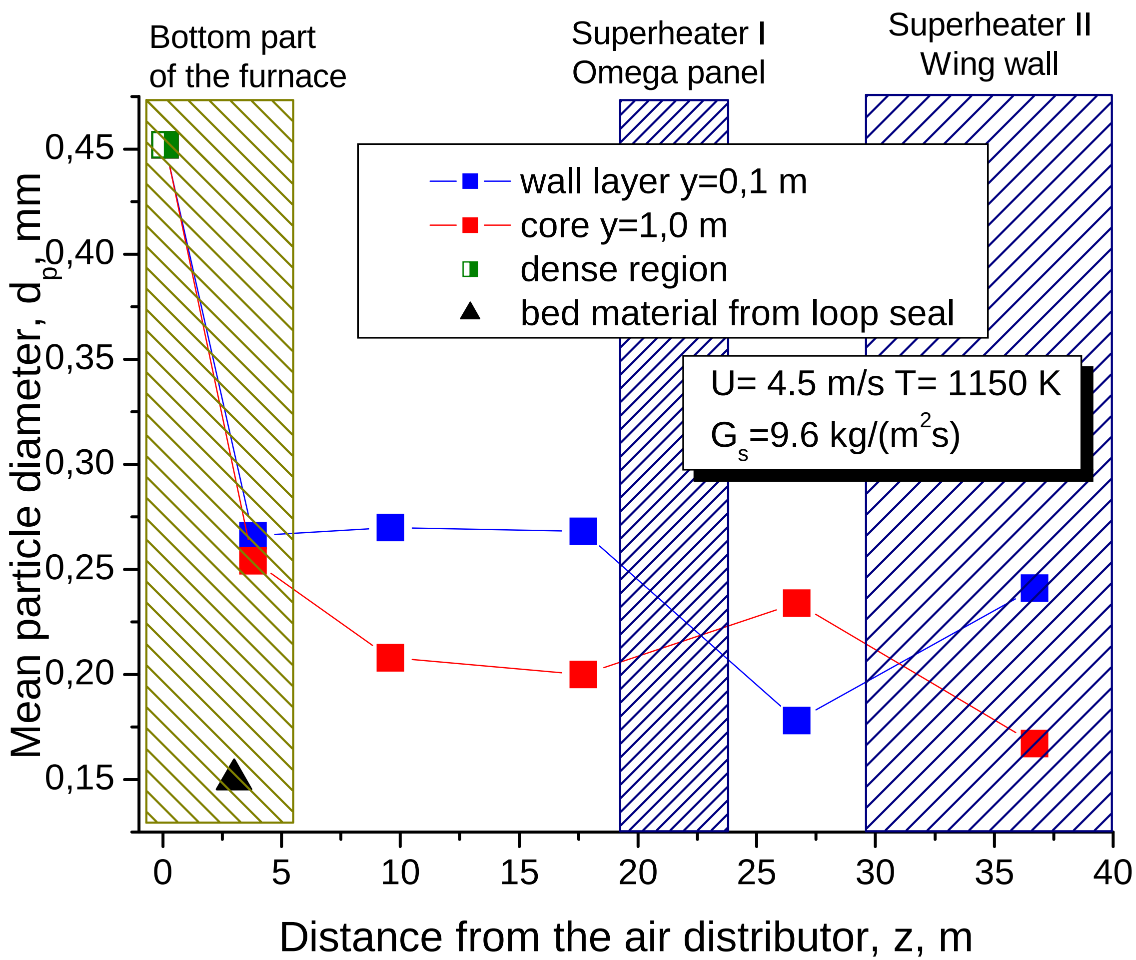
PRESSURE MEASUREMENTS





Power spectral density of pressure for dense region, dilute region and wind box

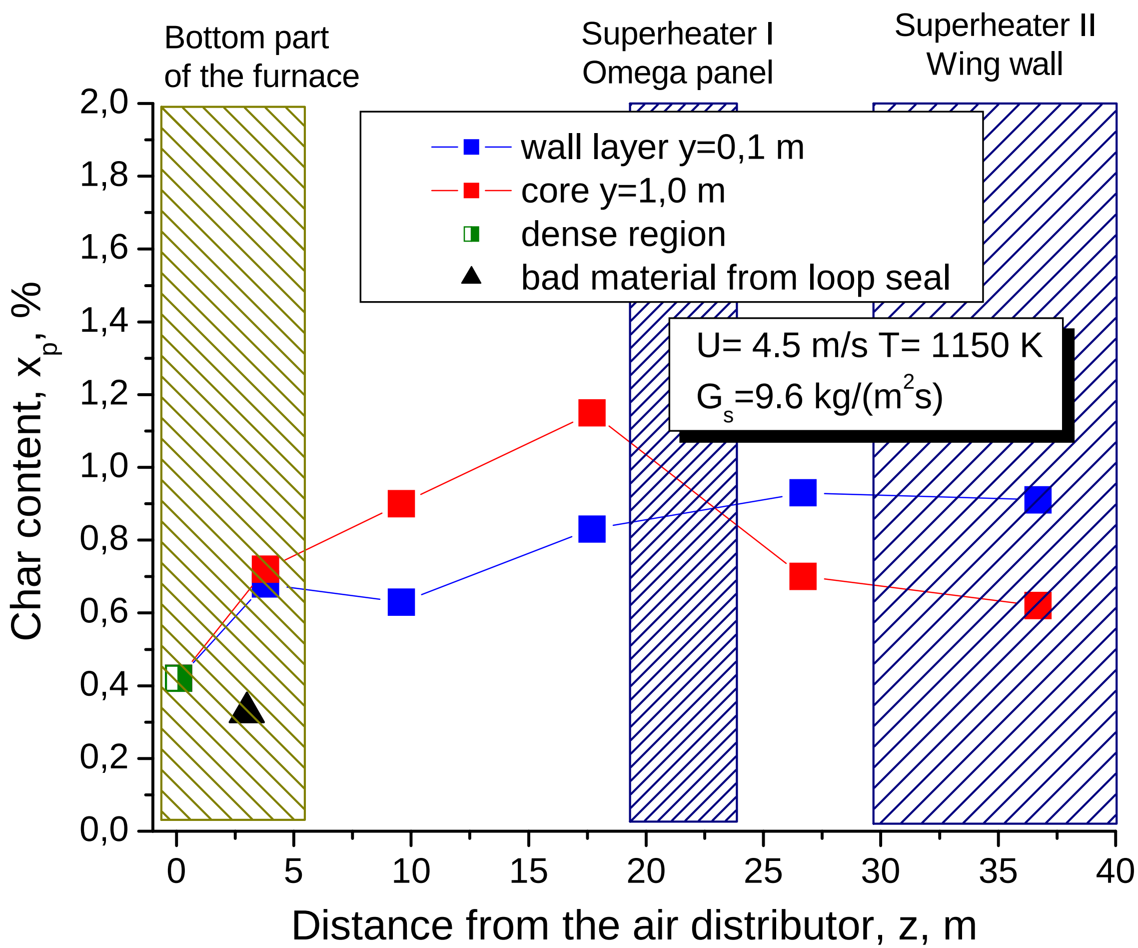
IN-FURNACE SOLIDS SAMPLING MEASUREMENTS



$$\bar{d}_p = \frac{1}{\sum_{all\ i} \left(\frac{x}{d_p} \right)_i}$$

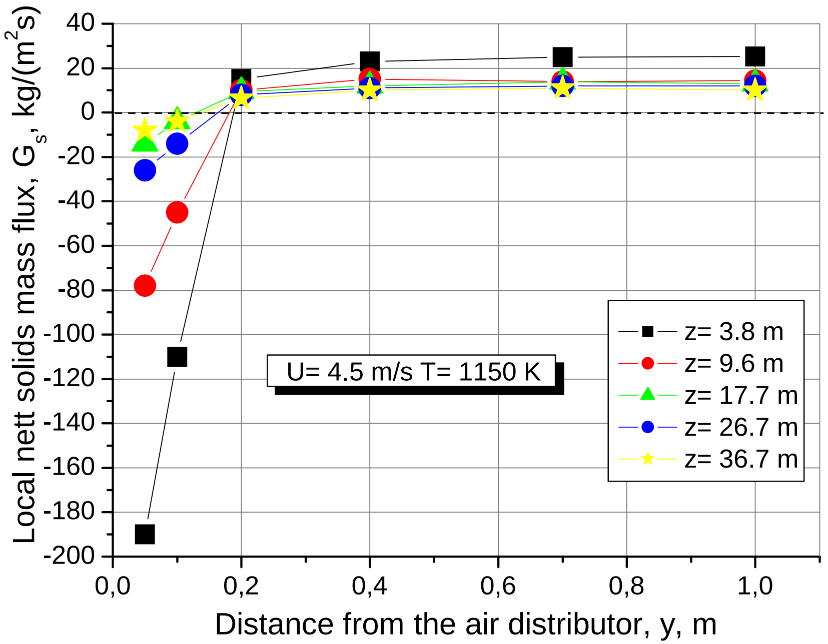
Mean particle diameter as function of distance from air distributor

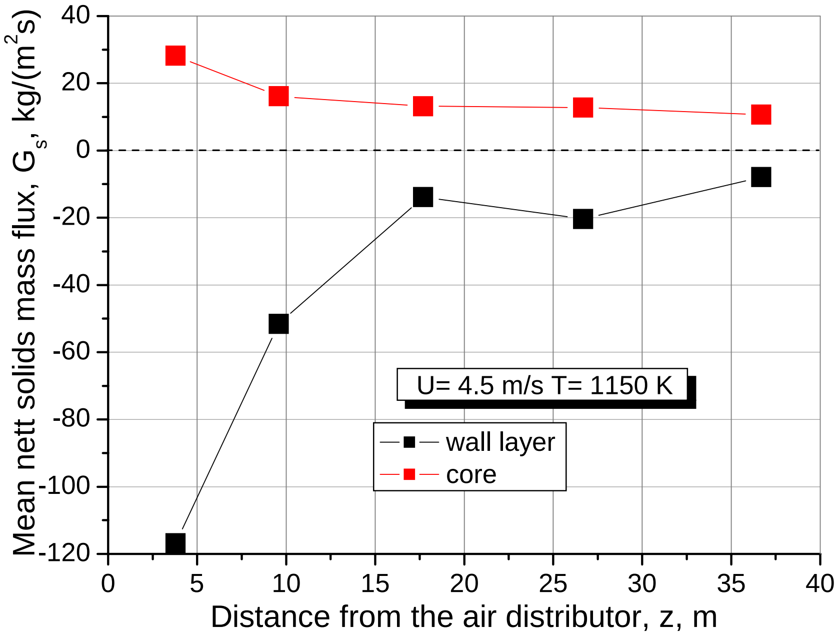
IN-FURNACE SOLIDS SAMPLING MEASUREMENTS



Char content as function of distance from air distributor

IN-FURNACE SOLIDS SAMPLING MEASUREMENTS



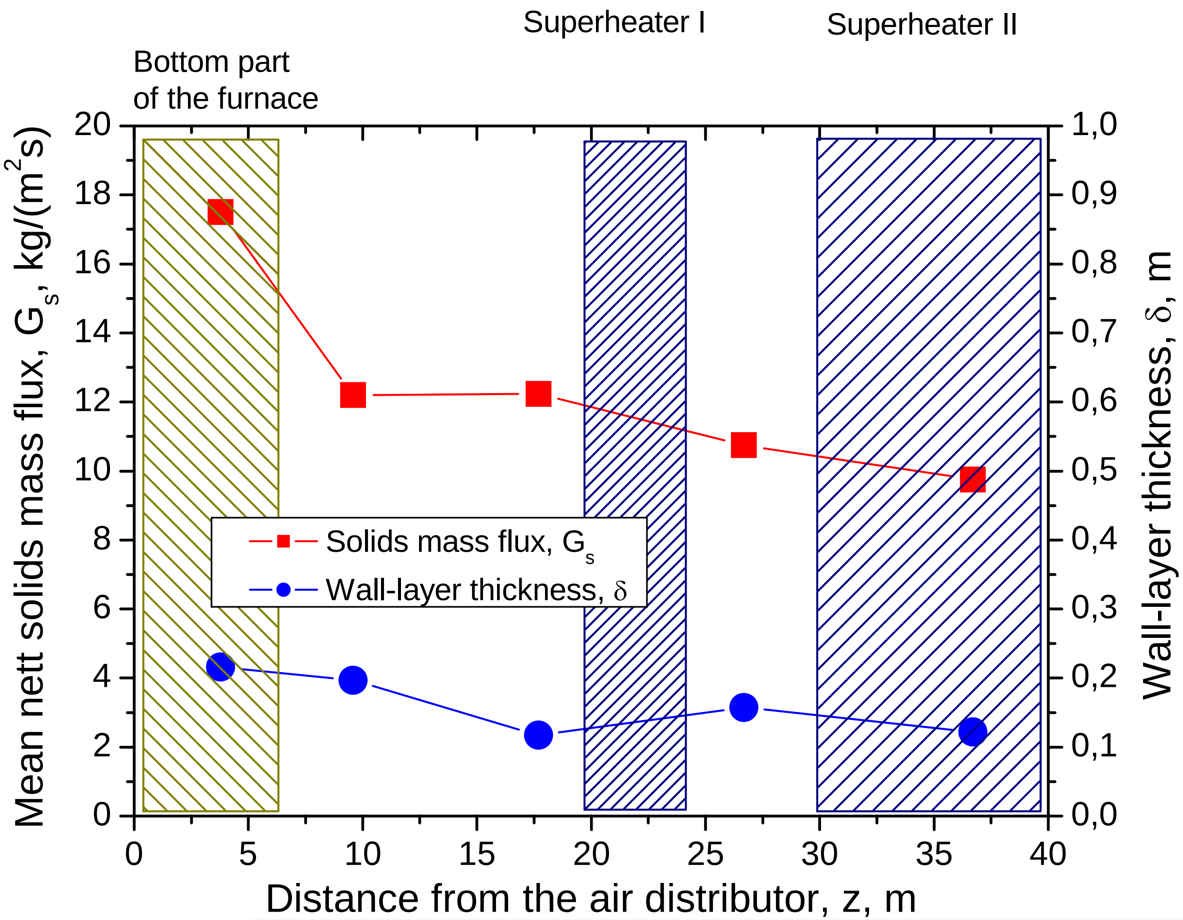


$$G_{s,p} = \frac{1}{\delta}\int_0^{\delta} G_{s,l}(x)dx$$

$$G_{s,r} = \frac{2}{D_e - 2\delta}\int_{\delta}^{D_e/2} G_{s,l}(x)dx$$

Solids mass flux

IN-FURNACE SOLIDS SAMPLING MEASUREMENTS



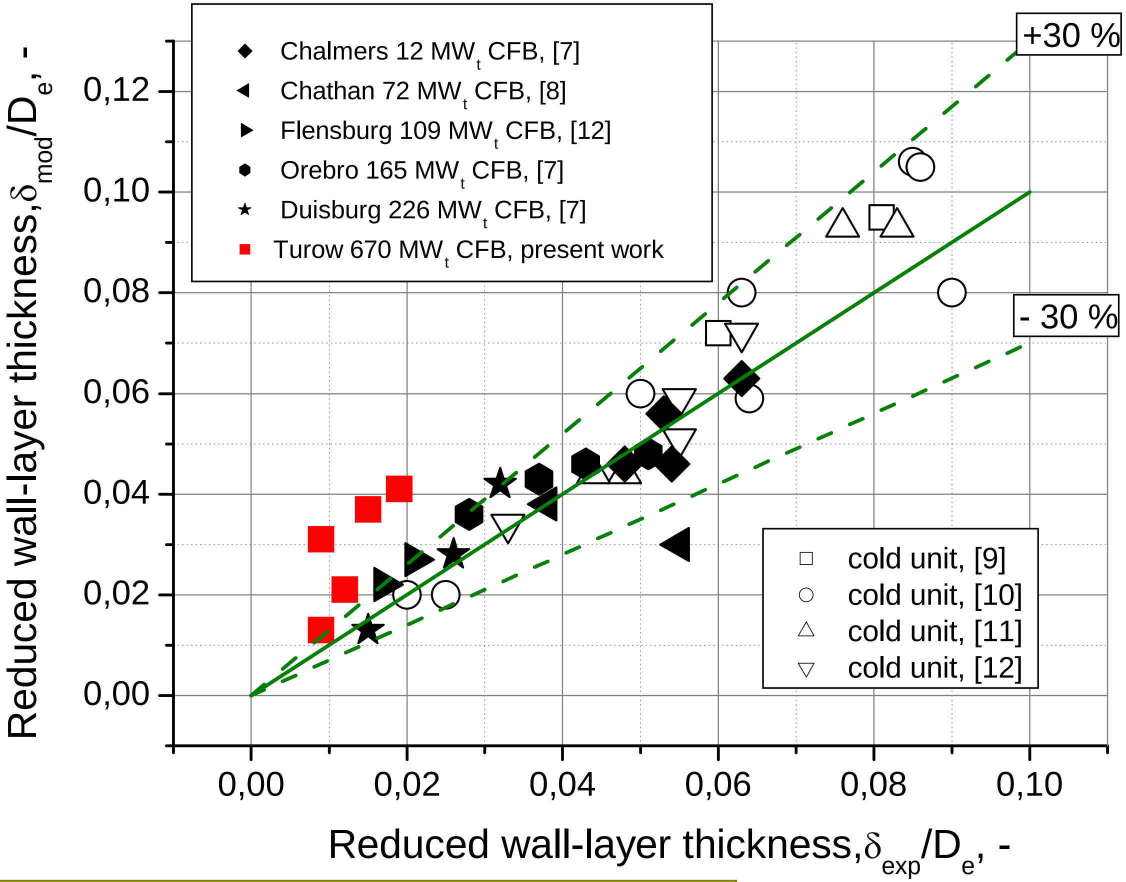
$$G_s = \frac{G_{s,r} \cdot A_r - G_{s,p} \cdot A_p}{A_k}$$

Turow CFB boiler - 670 MW_t, H/D_e=3,3, δ=0,17 m, x_d=5,5%

Chalmers CFB boiler - 12 MW_t, H/D_e=8,8, δ=0,10 m, x_d=25% [5, 6]

Solids mass flux and wall-layer thickness as function of distance from the air distributor

IN-FURNACE SOLIDS SAMPLING MEASUREMENTS



$$\delta = \left(0.55 \cdot \mathrm{Re}_t^{-0.22} \cdot \left(\frac{H}{D_e}\right)^{0.21} \cdot \left(\frac{H-h}{H}\right)^{0.73}\right) \cdot D_e \quad [13]$$

$$\mathrm{Re}_t = \frac{u \cdot D_e}{\nu}$$

Solids mass flux and wall-layer thickness as function of distance from the air distributor

CONCLUSIONS

1. The vertical distribution of solids four regions were identified in the furnace *as*: the bottom region, the dense region, the dilute region, and the exit region.
2. The measurements showed the existence of a bubbling fluidized bed in the bottom region.
3. The height of the bottom region and the solids volume concentration at the exit region were lower for the unit with a height-to-width (H/D_e) ratio of 3,3 than for the unit with larger value of the same parameter.
4. Dominant frequency for the bottom region was 0,39 Hz. The value was lower than for the units with larger value of H/D_e ratio.
5. Each region of the CFB was characterized by its own dominant pressure frequency.
6. It was also observed that there are very good conditions for mixing in the dense region of 670 MW_{th} CFB boiler. This leads to the uniform distribution of the bed material in the intersection of the bottom part of the combustion chamber.
7. In the core of dilute region, an intensive solids elutration phenomenon into the cyclones was observed, the coarse particles tend to accumulate close to the walls of the combustion chamber, thus indicating the existence of the core-wall layer flow in dilute region of a large scale CFB boiler.
8. The area occupied by the wall layer flow of a 670 MW_{th} unit was roughly 5 times less compared to the results obtained from a 12 MW_{th} CFB boiler.

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CONCLUSIONS 1/2

1. The vertical distribution of solids four regions were identified in the furnace *as*: the bottom region, the dense region, the dilute region, and the exit region.
2. At the superficial gas velocity of 4,5 m/s and the pressure drop of 7,58 kPa the average solids volume concentrations 0,38 was observed in the bottom region of the furnace. The height of the bottom region was 0,24 m.
3. The measurements showed the existence of a bubbling fluidized bed in the bottom region. The bubbling bed was characterized by the constant solids concentration regardless of a bed height.
4. It was found out that the height of the dense region was 3,05 m and the average solids volume concentration inside of that region was 0,14.
5. For the dilute region, *i.e*. up to 35,02 m above the air distributor, the average solids volume concentration of the bed material was 0,007.
6. The height of the bottom region and the solids volume concentration at the exit region were lower for the unit with a height-to-width (H/D_e) ratio of 3,3 than for the unit with larger value of the same parameter.
7. Dominant frequency for the bottom region was 0,39 Hz. The value was lower than for the unit with H/D_e ratio of 8,8.
8. No different relation between the dominant frequency of pressure fluctuation in the furnace and dominant frequency of pressure fluctuation in the air-feed system was found.

CONCLUSIONS 2/2

9. Each region of the CFB was characterized by its own dominant pressure frequency and pressure standard deviation of the bed particles. It was found out that for the upper regions of the CFB in the furnace the values of dominant frequency and standard deviation were lower.
10. In the core region of the combustion chamber, an intensive solids elutration phenomenon into the cyclones was observed, the coarse particles tend to accumulate close to the walls of the combustion chamber, thus indicating the existence of the core-wall layer flow in dilute region of a large scale CFB boiler combustion chamber.
11. It was also observed that there are very good conditions for mixing in the bottom part of the chamber. This leads to the uniform distribution of the bed material in the intersection of the combustion chamber.
12. On the basis of the results of the pressure measurements, as well as through the analysis of the bed material samples, one may observe the segregation process of the bed material along the height of the combustion chamber with the circulating fluidized bed.
13. The area occupied by the wall layer flow of a 670 MW_{th} unit was roughly 5 times less compared to the results obtained from a 12 MW_{th} CFB boiler.