Modeling of the bed inventory in CFB boilers

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In collaboration with Metso Power
Project: ”An overall CFB model”

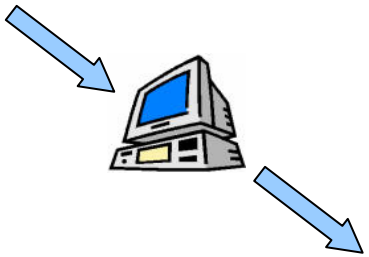
Modeling of the bed inventory in CFB boilers

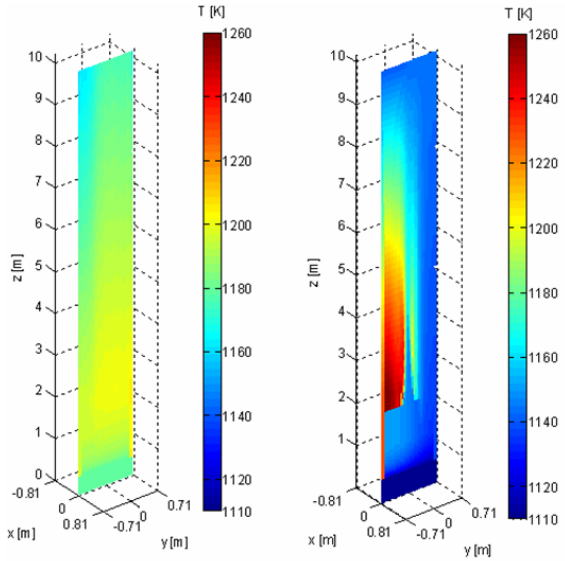
- **Background**
- **Solids inventory control**
- **Modeling**
- **Results**

Overall CFB model - concept

Inputs

- Geometry of the circulating loop
- Operational conditions
  - Fuel flows (rate, location, composition, temperature, frag)
  - Air flows (rate, location, composition, temperature)
  - Furnace pressure drop
  - Steam data
- Solids properties (PSD, density, sphericity)





Outputs

Concentration fields (gases & solids)

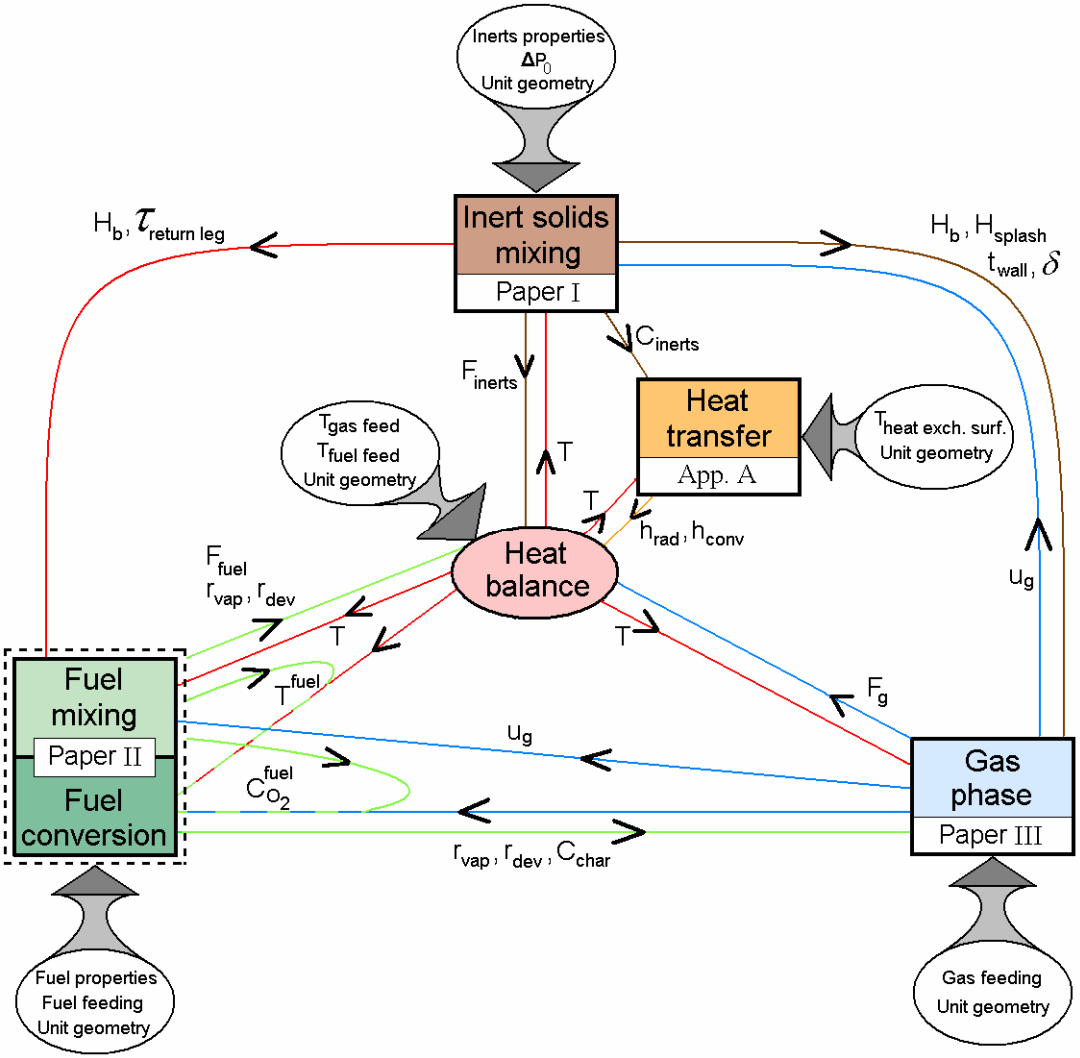
Mass flux fields (gases & solids)

Temperature field

Heat flux field

- Design tool
- Knowledge source
- Training tool

Overall CFB model - modules

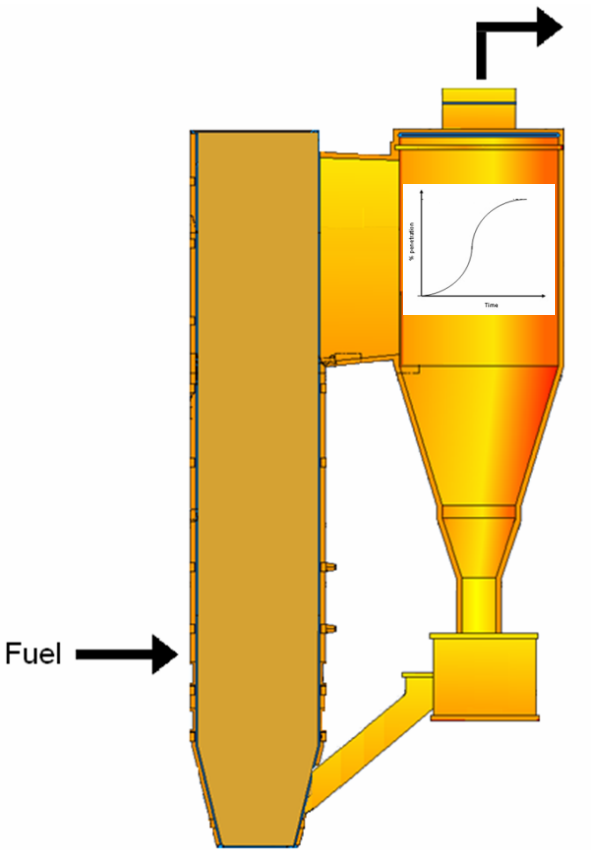


Overall CFB model - inputs

- Geometry of the circulating loop
- Operational conditions
  - Fuel flows (rate, location, composition, temperature, fuel frag.)
  - Air flows (rate, location, composition, temperature)
  - Furnace pressure drop
  - Steam data
- Solids properties (**PSD_{unit}**, density, sphericity)

Influences the fluiddynamics strongly
Often difficult to guess or measure ⇨ Needs to be modeled

Solids inventory



The bed solids inventory (or at least a representative part of it) is usually meant to consist of fuel ash (+sorbent).

Without acting on the bed solids inventory, it would tend to zero or (most likely) to fill up the riser, depending on:

- PSD
- Operational conditions
- Cyclone performance

Control strategies

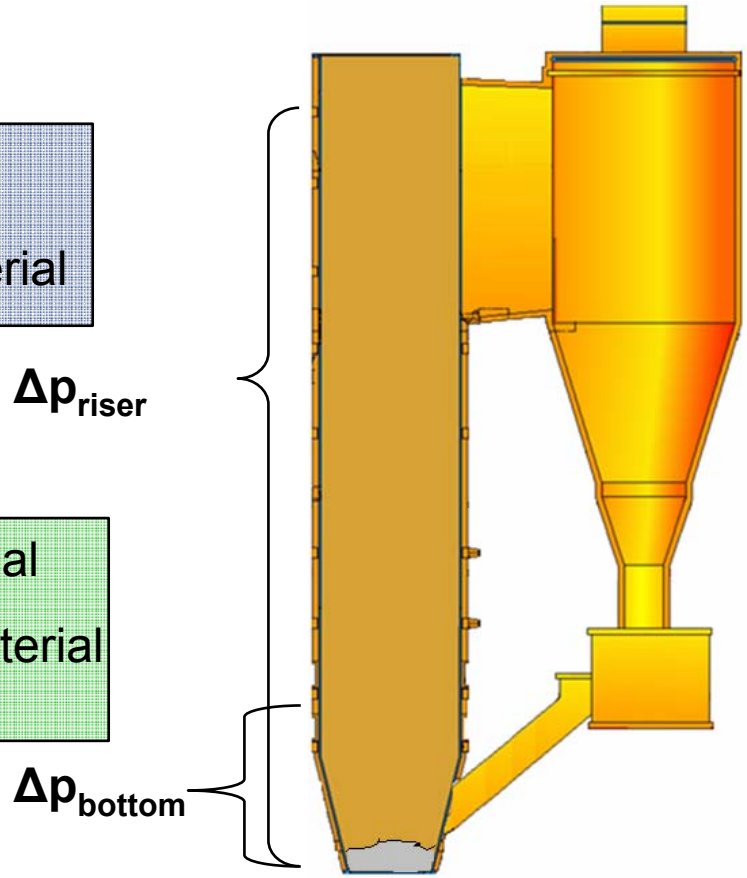
Usual measures to control the bed solids inventory

High Δp_{riser} → - Removal of bottom bed material

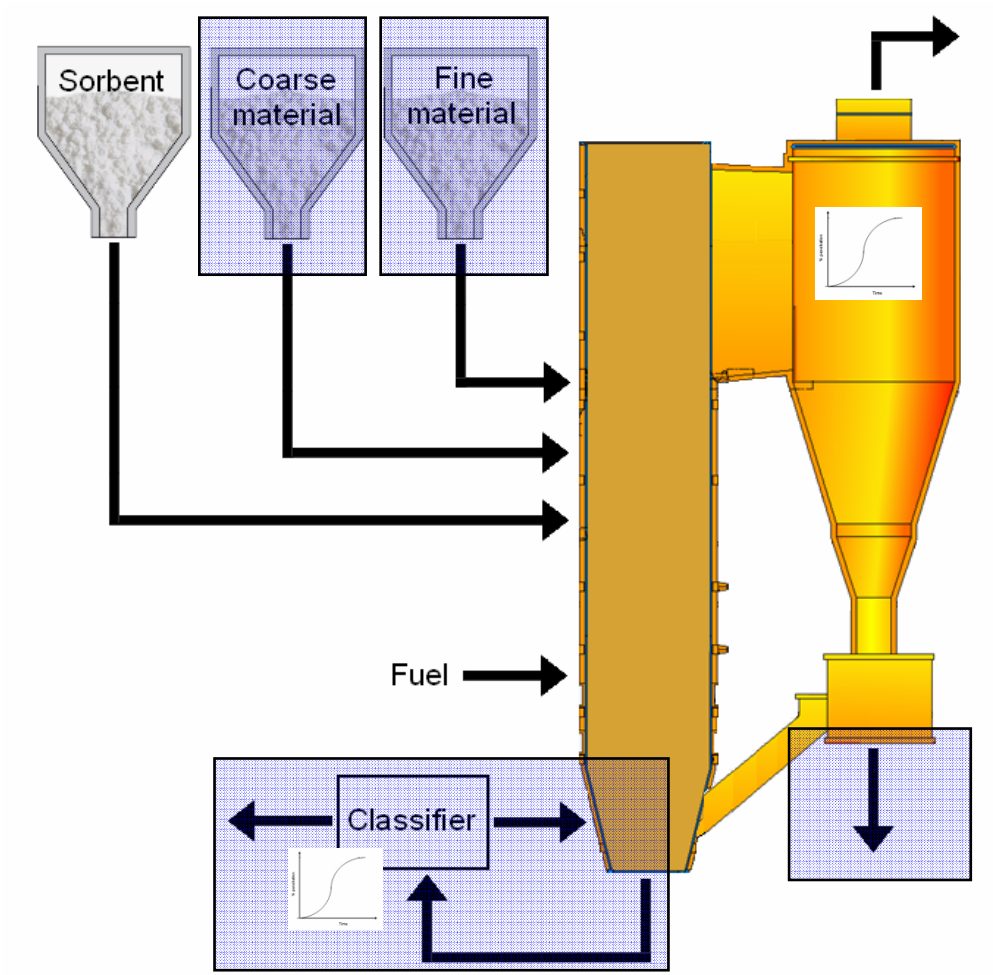
Low Δp_{riser} → - Addition of coarse makeup material

High Δp_{bottom} → - Addition of fine makeup material

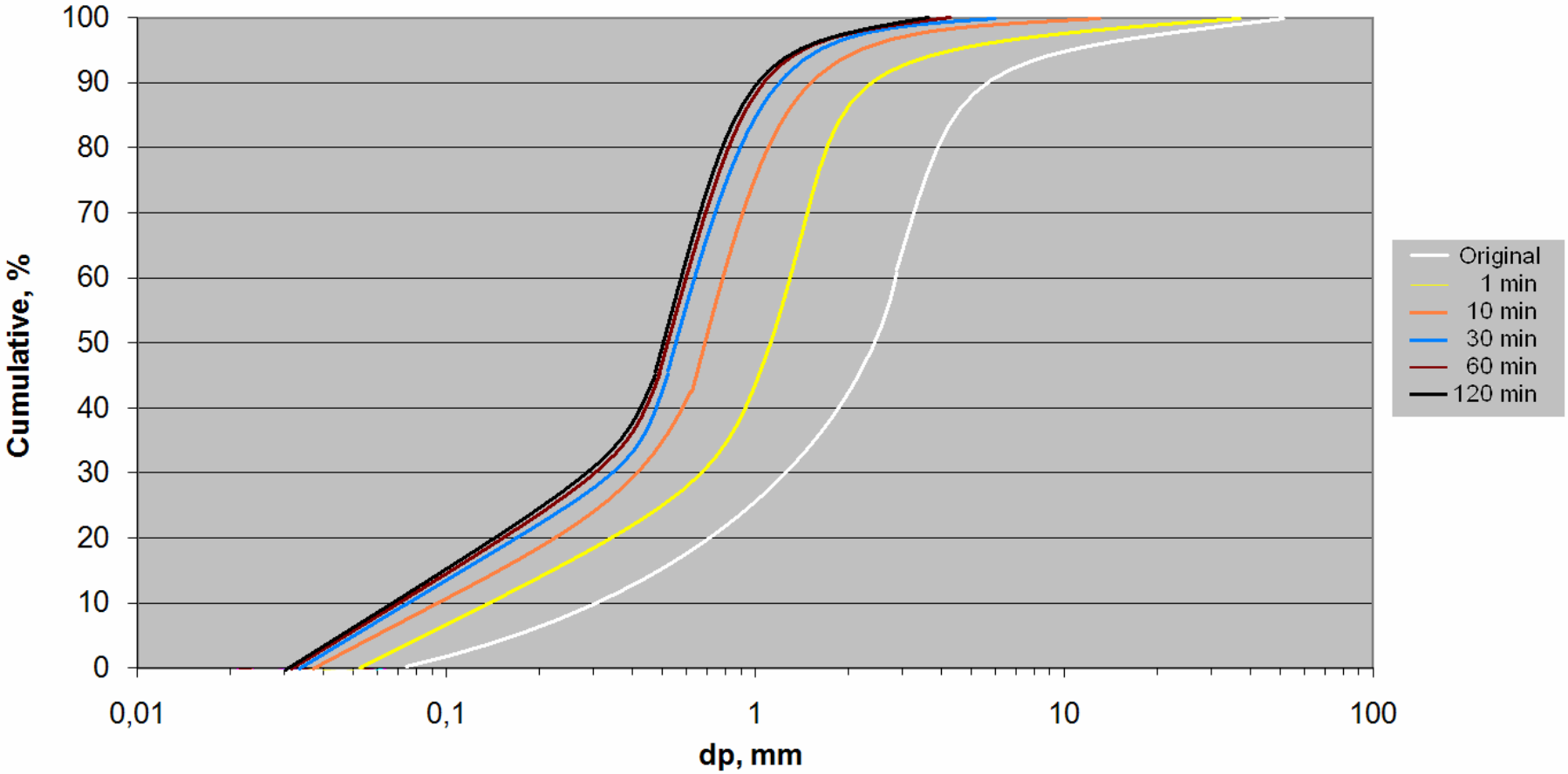
Low Δp_{bottom} → - Addition of coarse makeup material
- Removal of fine bed material



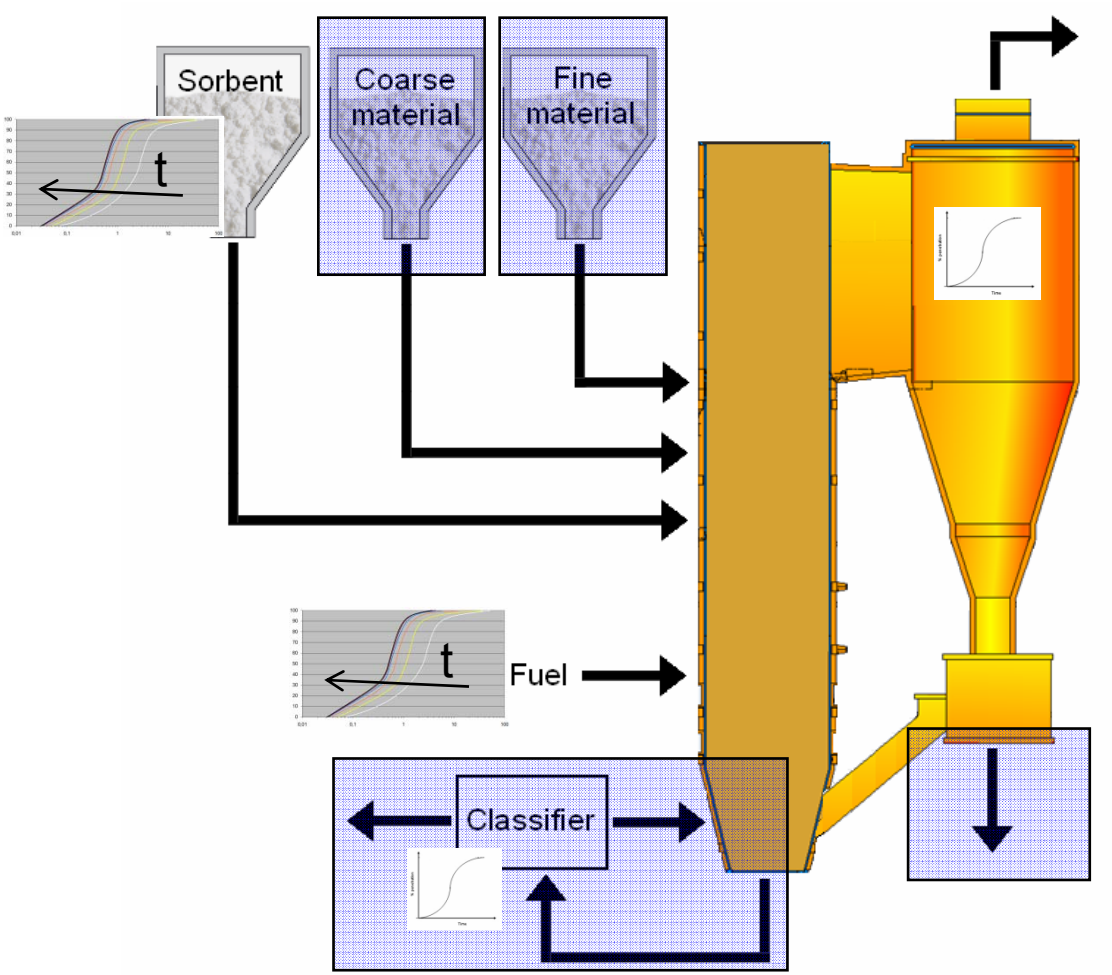
Control strategies



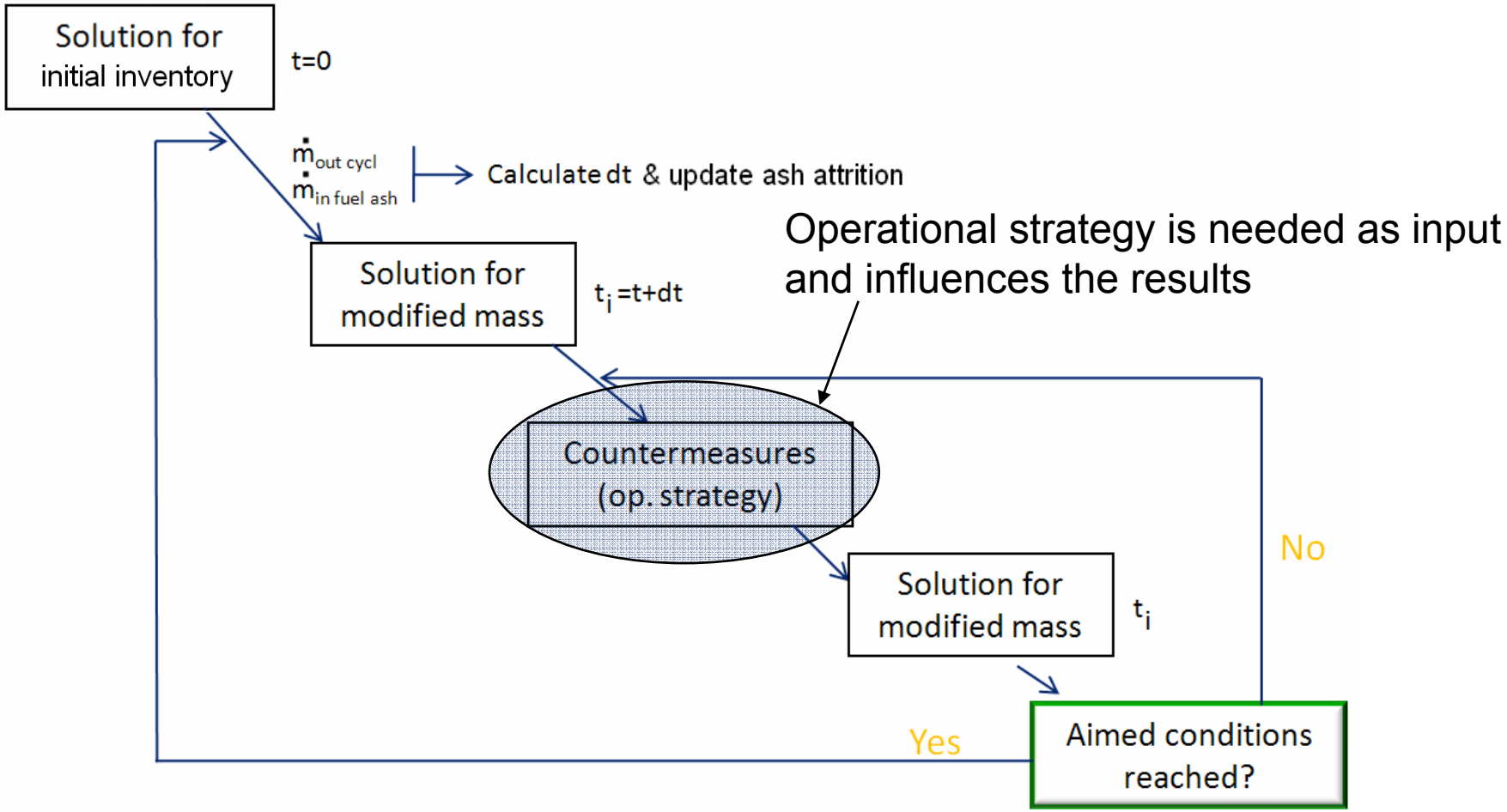
Solids attrition



Control strategies



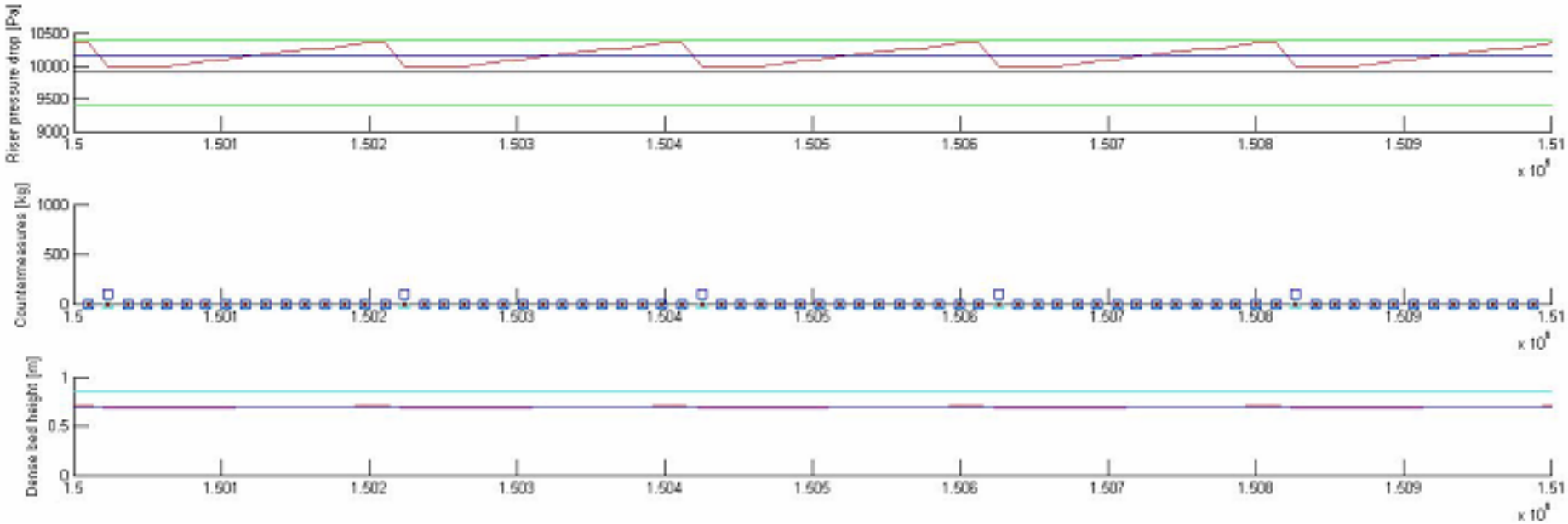
Transient modeling



Pseudo-steady state

With control strategies of *sudden* nature, a steady state is never reached.

However, a pseudo-steady state is finally reached in which a pattern of countermeasures is repeated at a constant frequency. The main fluiddynamical parameters keep oscillating slightly around their time-averaged values.



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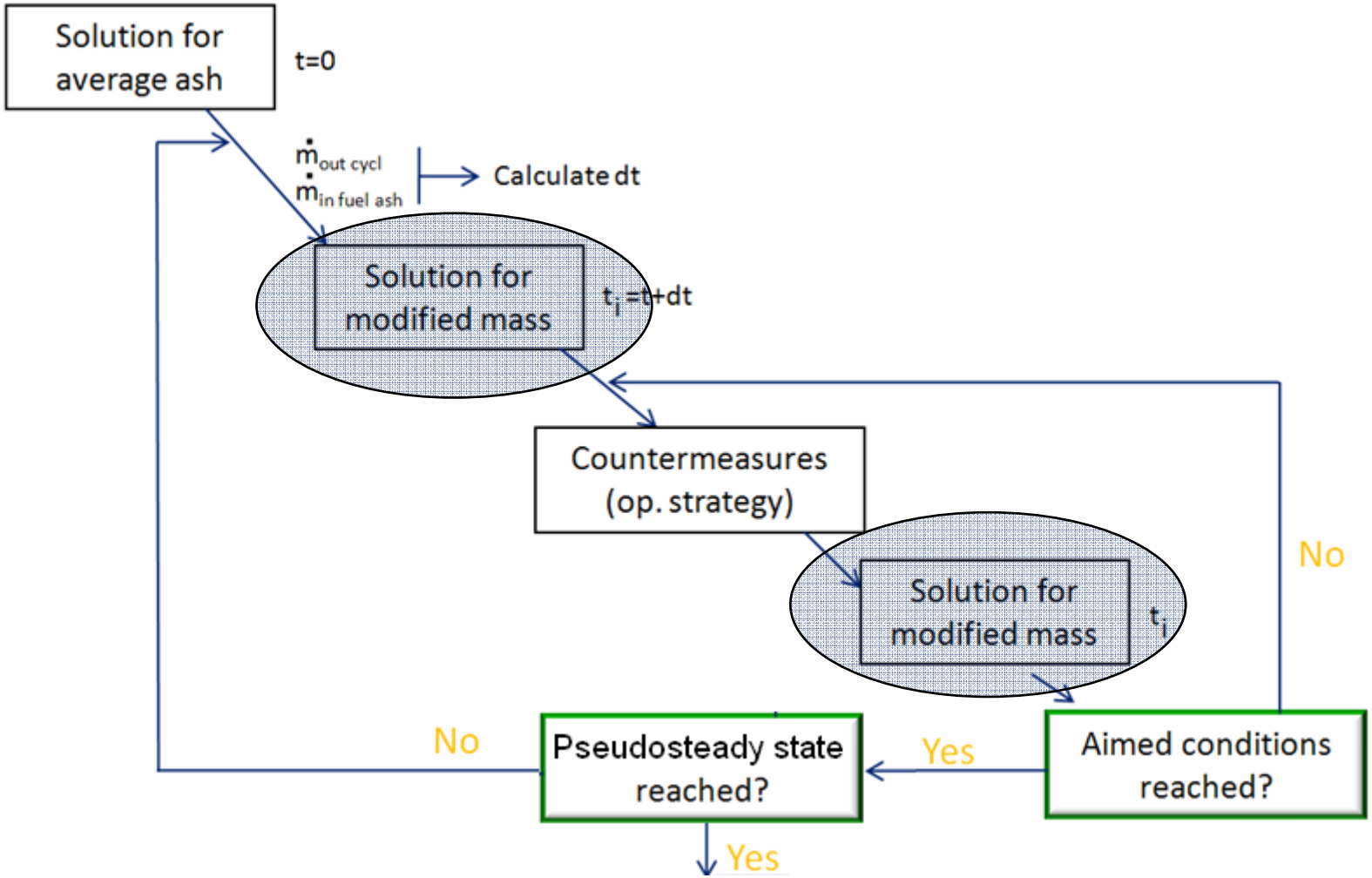
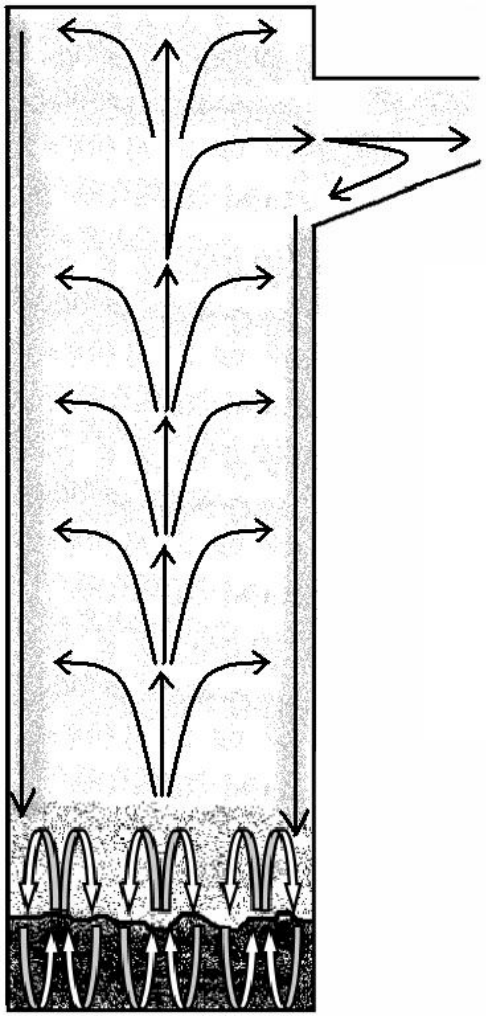
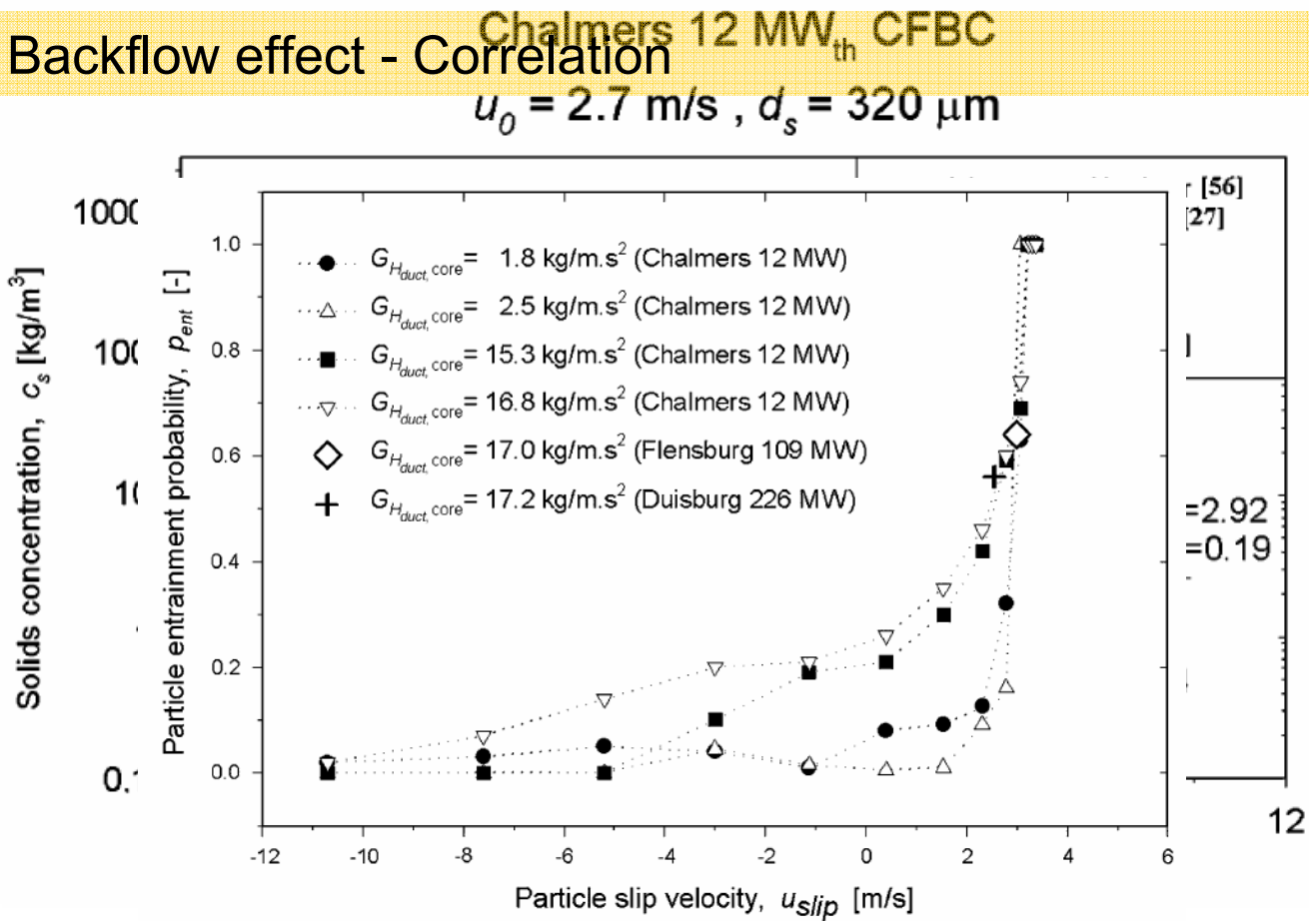


Solids mixing - furnace

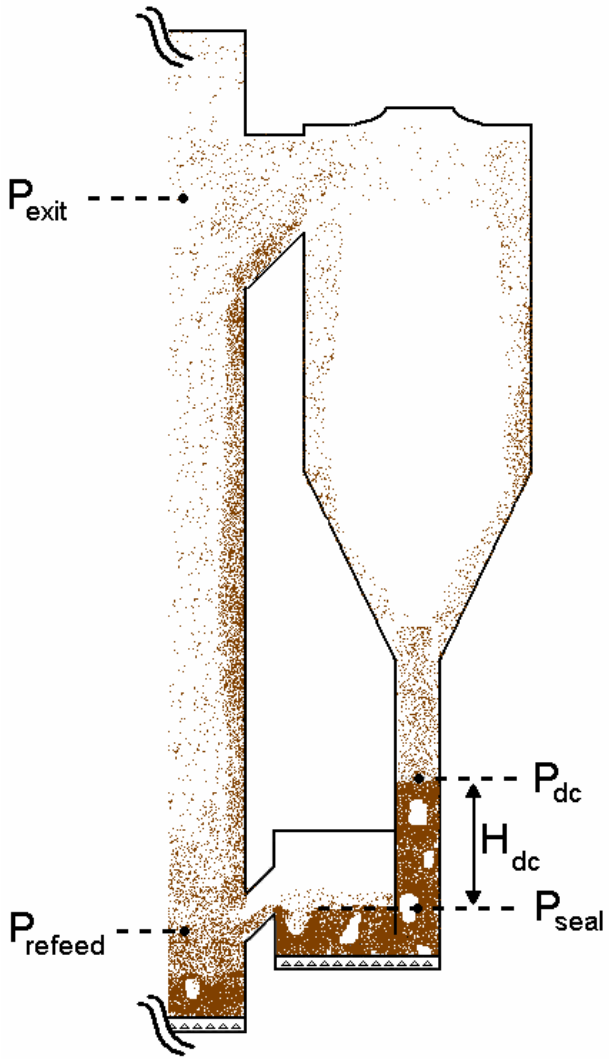


Cluster & disperse phases (Johnsson and Leckner)

Backflow effect - Correlation



Solids mixing – return leg



Pressure balance on circulating loop

↓

$P_{seal} - P_{dc}$

↓

H_{dc}

↓

m_{dc}

↓

Population balance on circulating loop

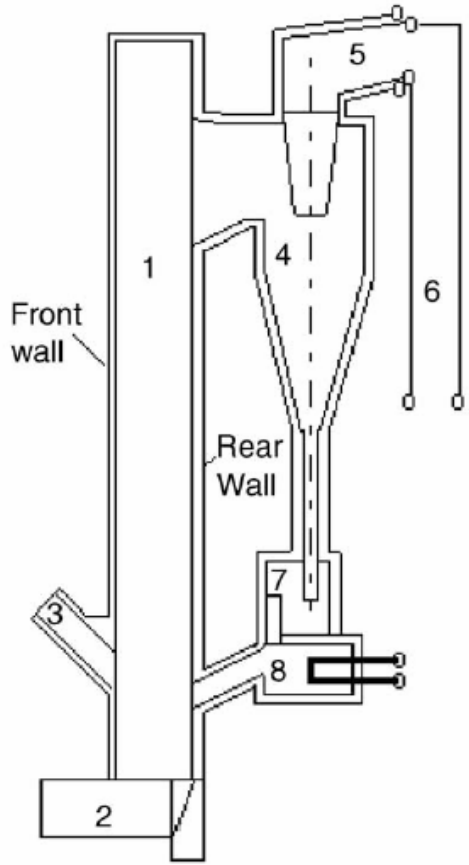
Results – 4 parameters studied

Chalmers CFB boiler (12 MW_{th})

16 cases studied

No sorbent

Fuel ash content [-]	0.005	0.25
Attrition time (h)	1	10
Cyclone efficiency	high	low
dp_bot control	on	off



Results – Control strategies used

Δp_{riser} -related

Countermeasures applied if experimental value deviates >5% from nominal value

$\Delta p_{riser,exp} > \Delta p_{riser,nom}$: Bottom bed material removal

$\Delta p_{riser,exp} < \Delta p_{riser,nom}$: Coarse worn-out material addition

Δp_{bottom} –related (Δp_{bottom} measured between h=0.135 and h=1.635 m)

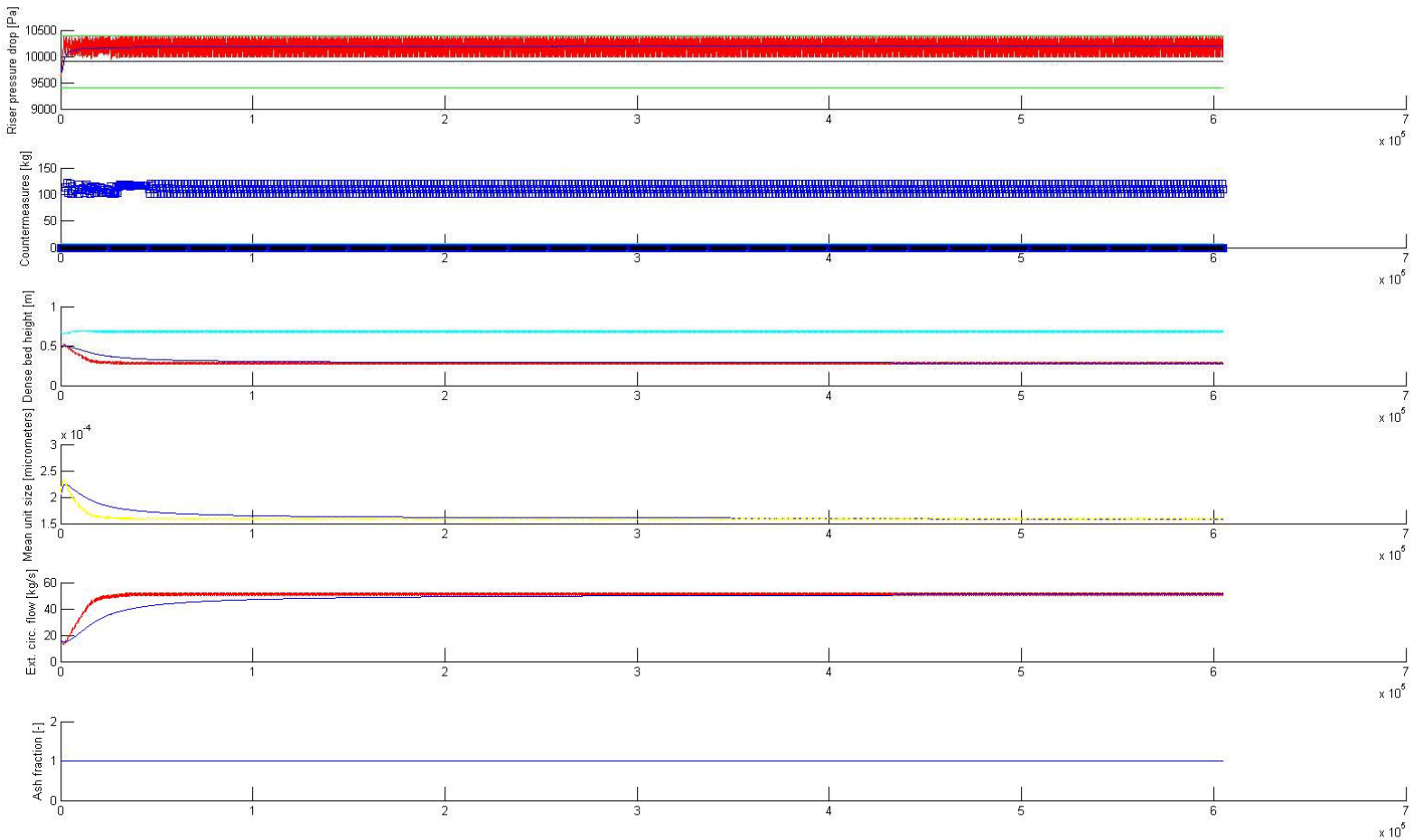
Countermeasures applied if experimental $\alpha=\Delta p_{bottom}/\Delta p_{riser}$ is outside range 0.40-0.82

$\alpha < 0.40$: Coarse worn-out material addition and bottom bed material removal
(no removal from seal available at Chalmers boiler)

$\alpha > 0.82$: Fine worn-out material addition and bottom bed material removal

Bed material modeling

High-efficiency cyclone (slow attrition, $x_{ash,fuel}\uparrow$)



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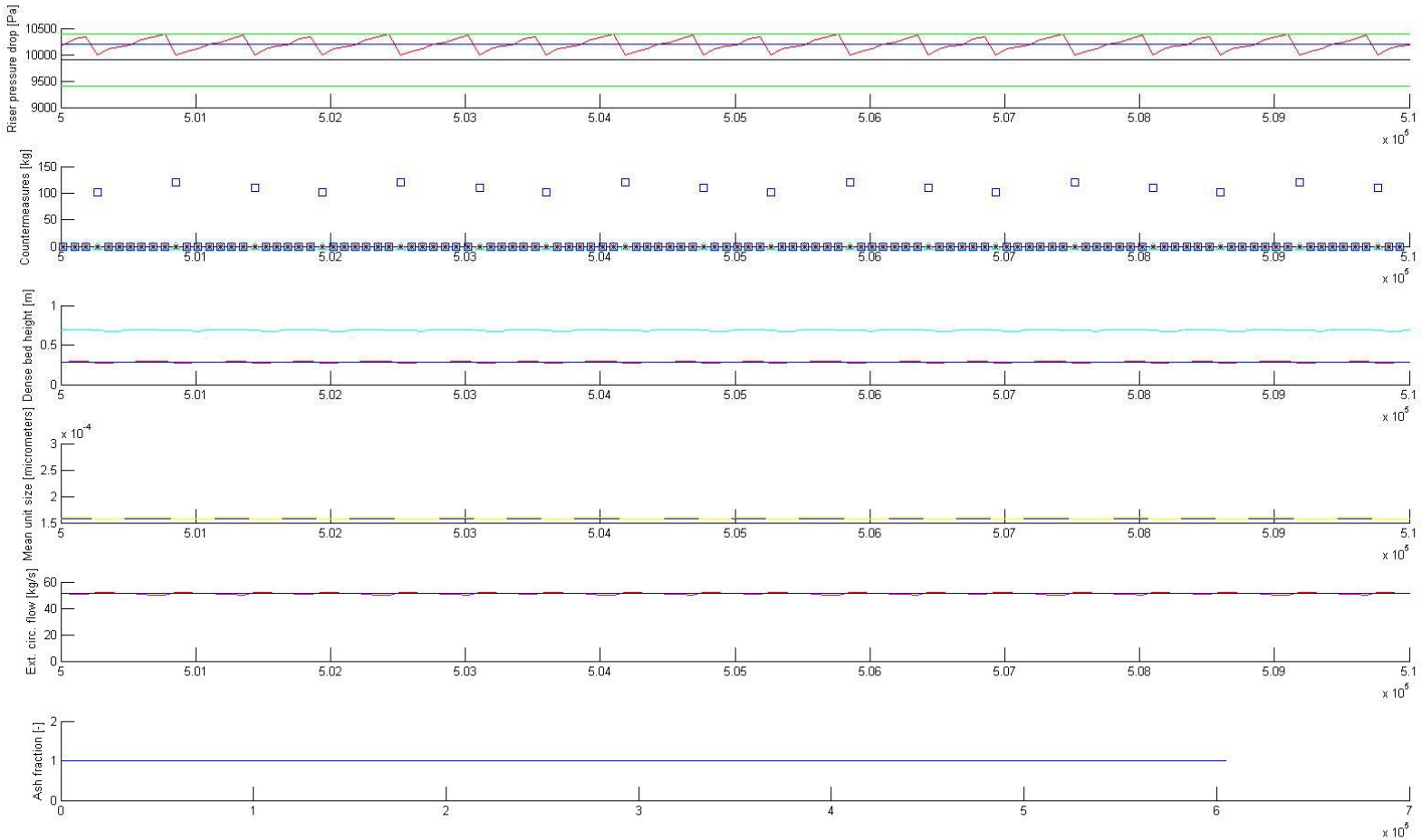


Conclusions (η_{cycl} ↑)

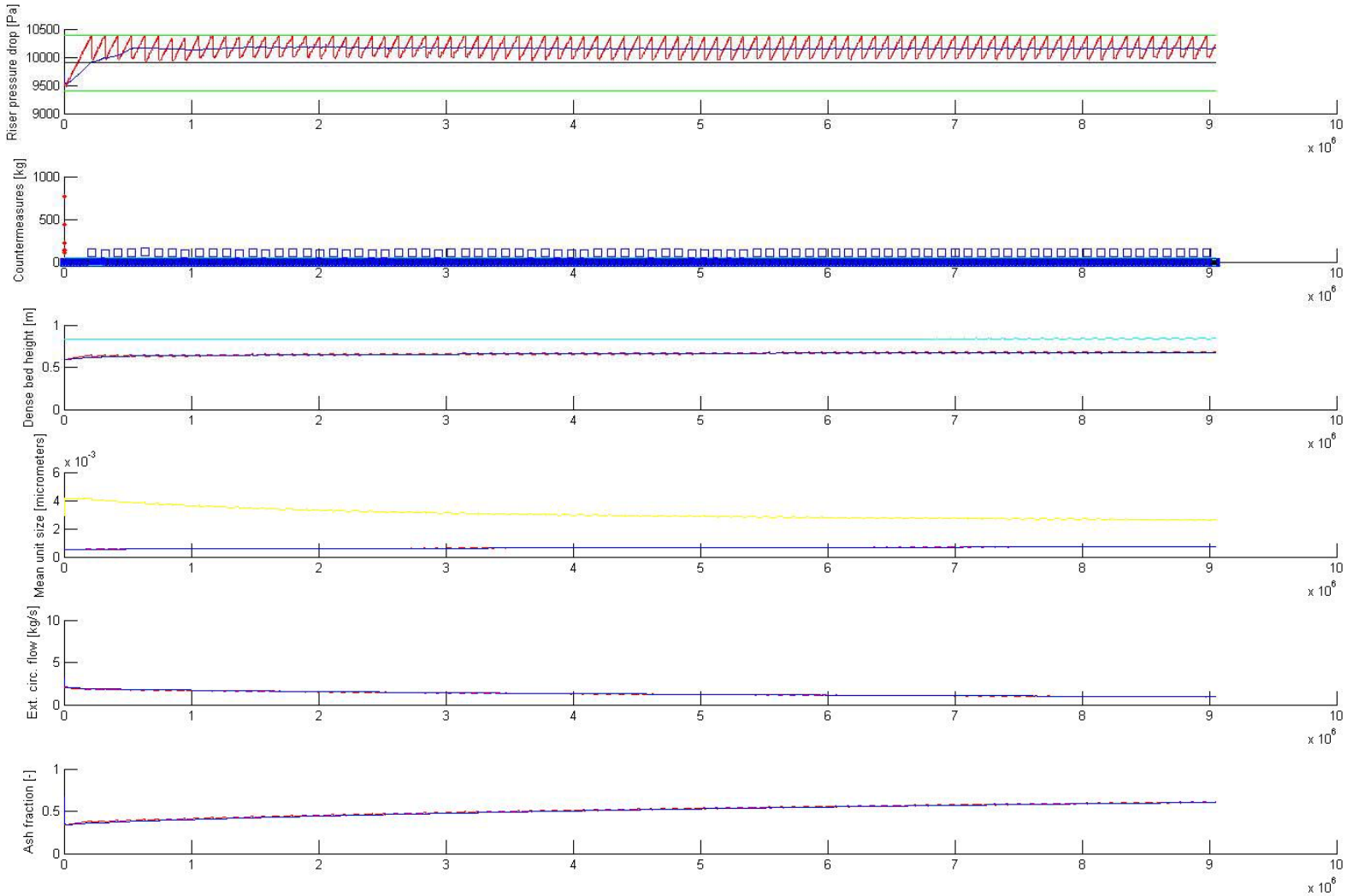
- In all runs, relatively similar pseudo-steady state values for:

  PSD_{unit}, H_b, $F_{s,net}$

- Limited influence of the attrition rate also on all other variables
- F_{stack},F_{class} α $x_{ash,fuel}$ → F_{stack}/F_{class}~constant
- High $x_{ash,fuel}$ leads to sooner pseudosteady states

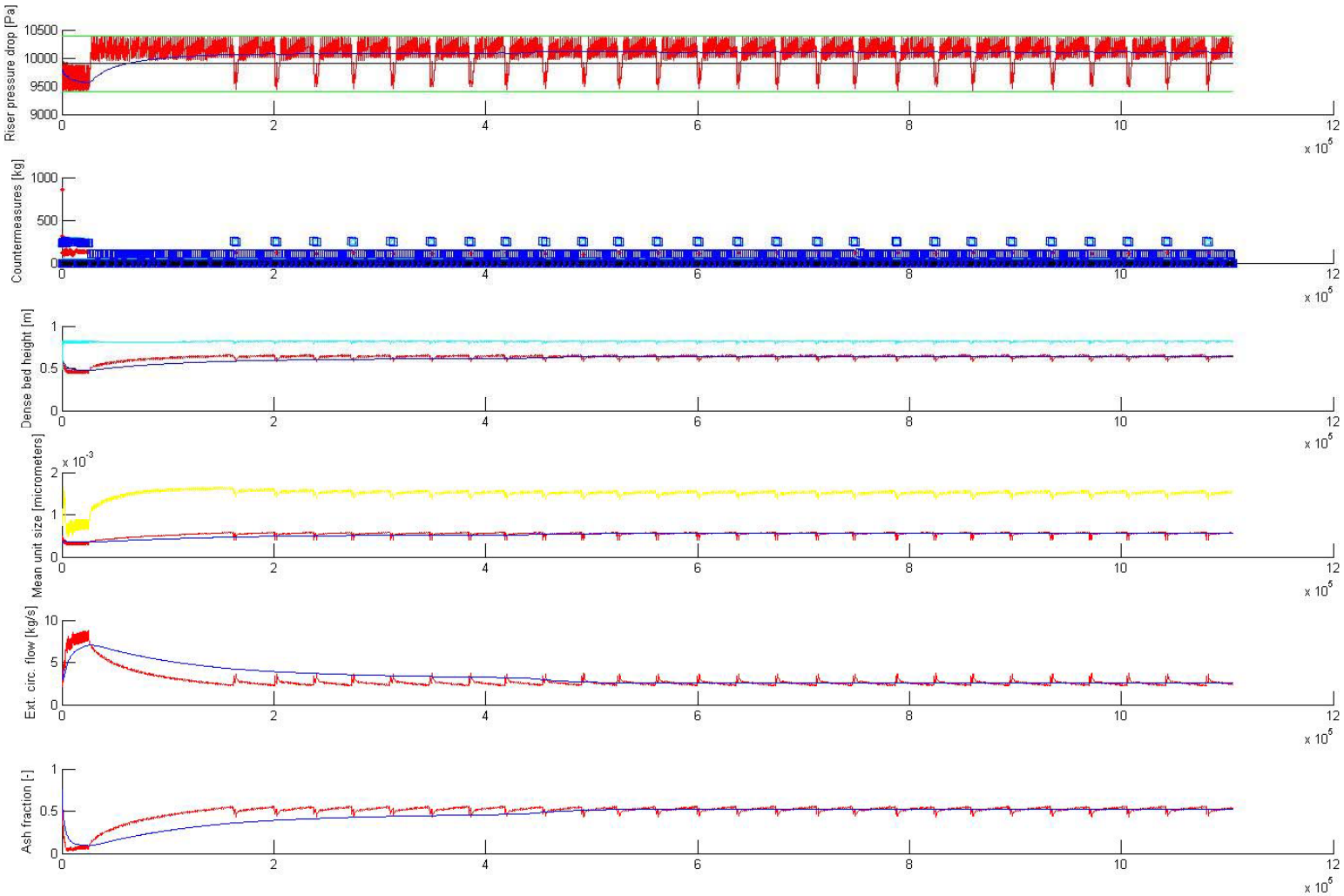
Bed material modeling

Low-efficiency cyclone, no Δp_{bot} control (slow attrition, $x_{ash,fuel}\downarrow$)



Bed material modeling

Low-efficiency cyclone, Δp_{bot} control (slow attrition, $x_{ash,fuel}\uparrow$)



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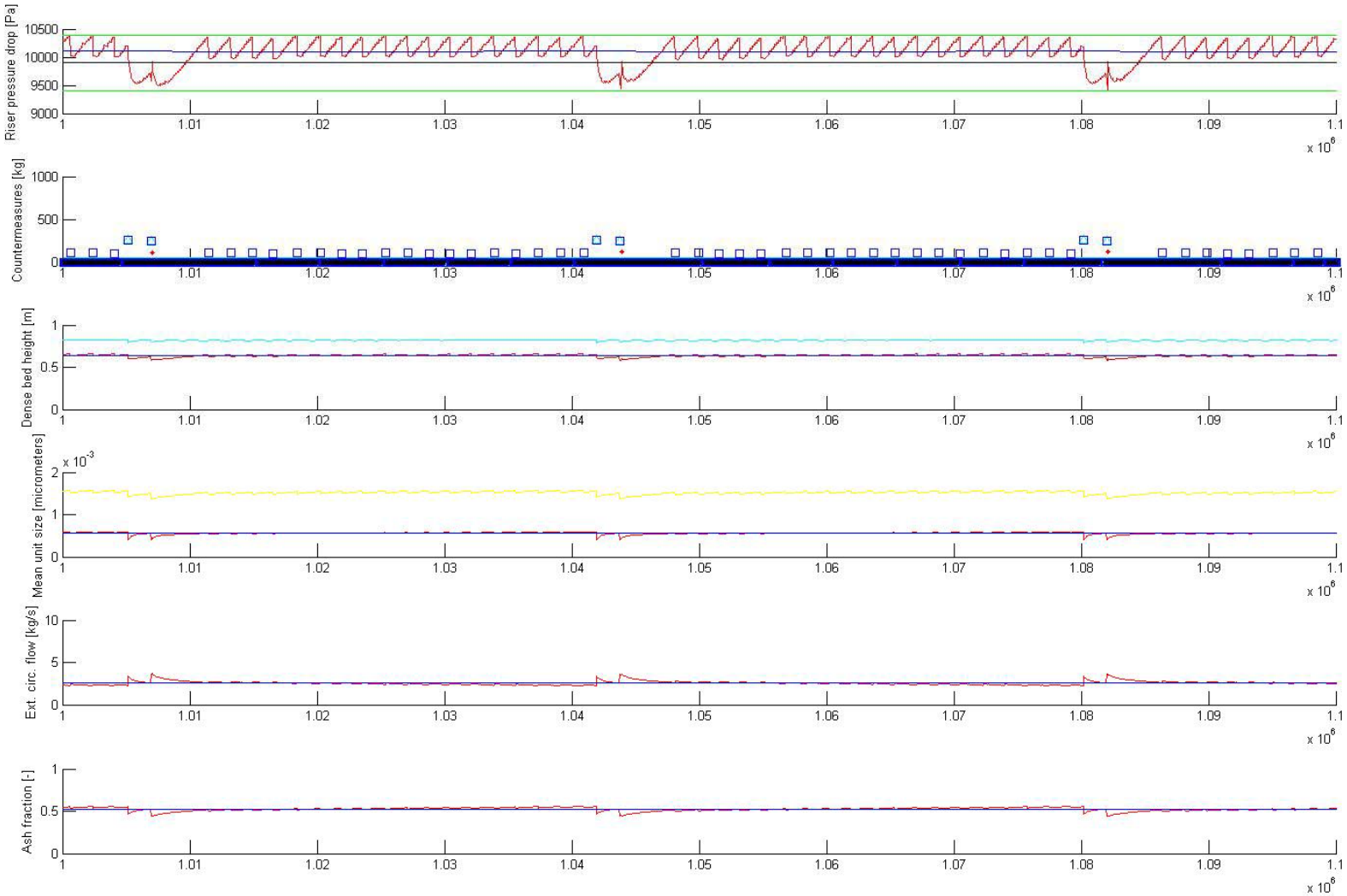


Conclusions ($\eta_{cycl} \downarrow$)

- For all cases

  Higher attrition rates imply increased need of makeup material (and thereby changes in the fluiddynamics).

- Without Δp_{bot} control

  The unit tends very slowly to a pseudo-steady state in which all bed material is formed by coarse, non-circulating ash. Only fines from attriting ash are entrained and go to stack.

- With Δp_{bot} control

  The PSDs of added materials govern the pseudo-steady state. This influence increases as $x_{ash,fuel}$ decreases.

Conclusions

- A model for the solids bed inventory is built. It has a dynamical approach and provides PSD_{unit} as well as solids flows within the CFB loop and in/out from the CFB unit (bottom/seal removal, stack, makeup).
- Cyclone performance is the most influential parameter and governs how other parameters influence the results
- Attrition rate influence increases as cyclone separation efficiency decreases
- Resolution and accuracy for finest sizes (*ie* η_{cycl} , $PSD_{plateau}$) is crucial

Further work

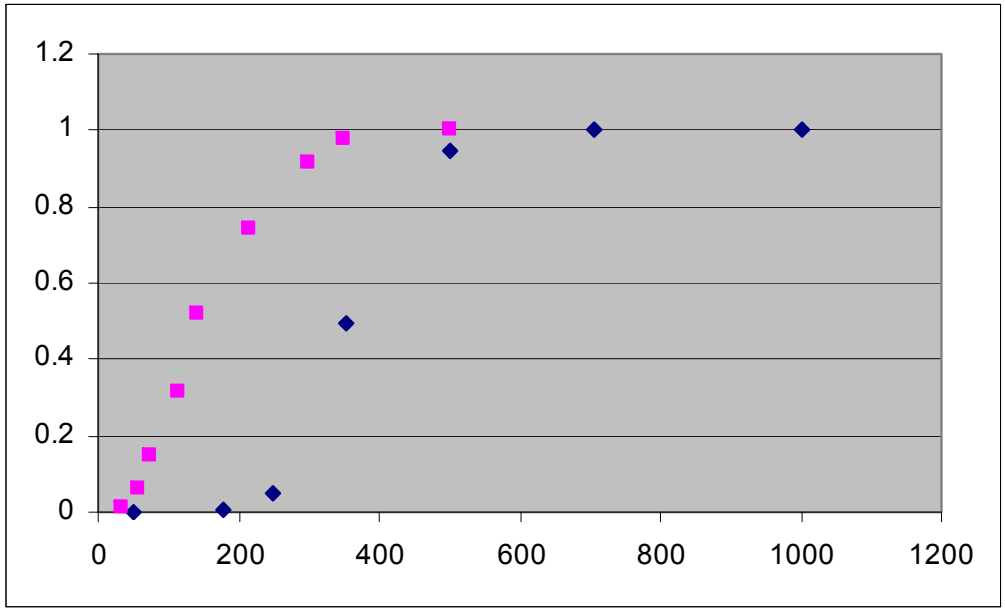
- The model will be within short tested against experimental data from large-scales CFB boilers

Thank you for your attention!
Questions?

Bed material modeling

Inputs needed

- $\dot{m}_{fuel}$, $x_{ash,fuel}$
- Ash attrition pattern
- PSD of coarse and fine material
- $\eta_{cyclone}(d)$, $\eta_{classifier}(d)$
- Control strategy



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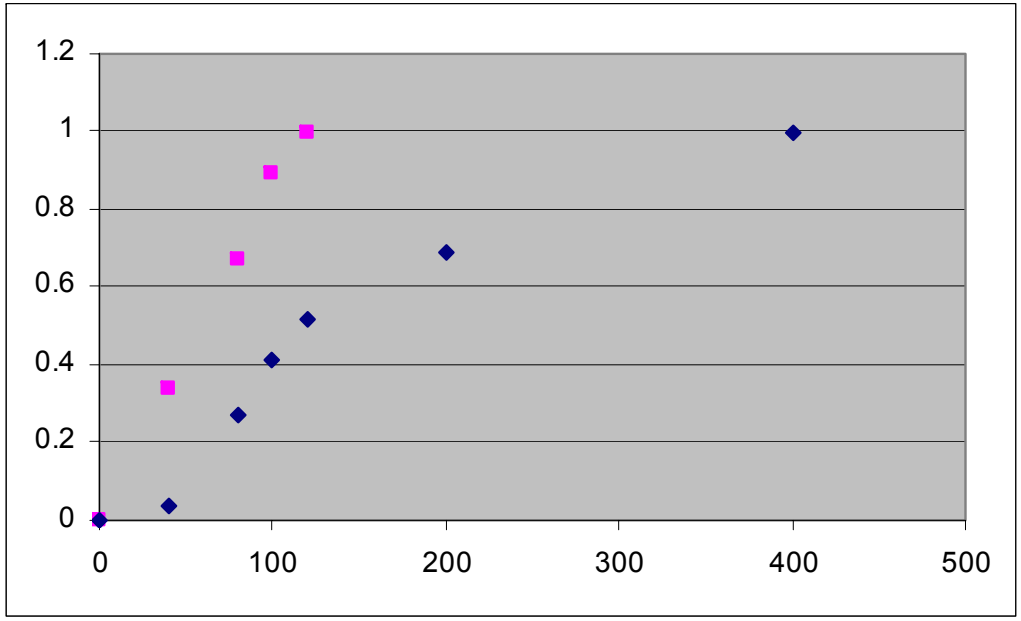

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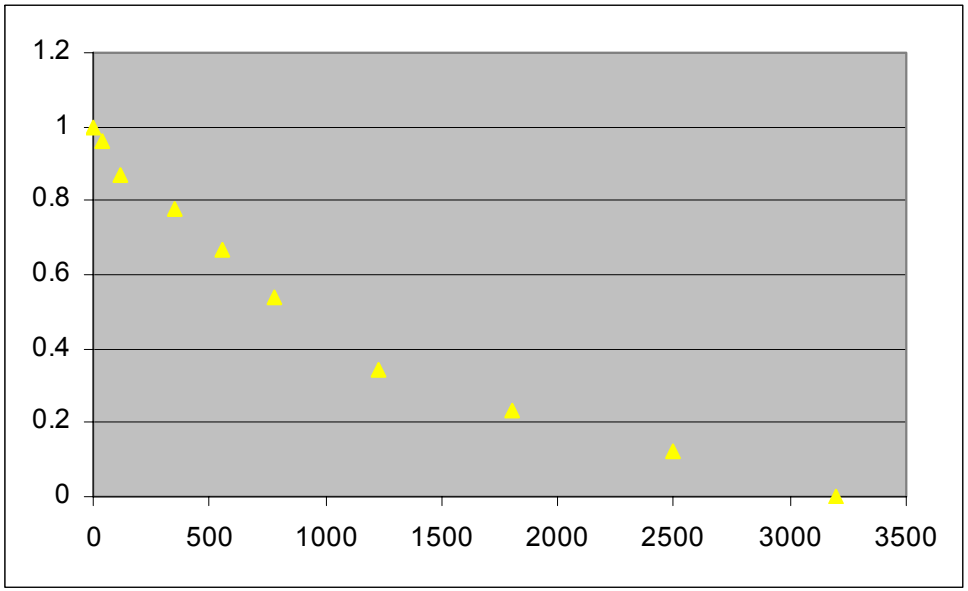

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$\Delta p_{riser,exp}$ 5% deviation tolerance

α [0.40,0.82]