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Dynamic flowsheet simulation of gas and solids flows in a system of coupled fluidized bed reactors for chemical looping combustion

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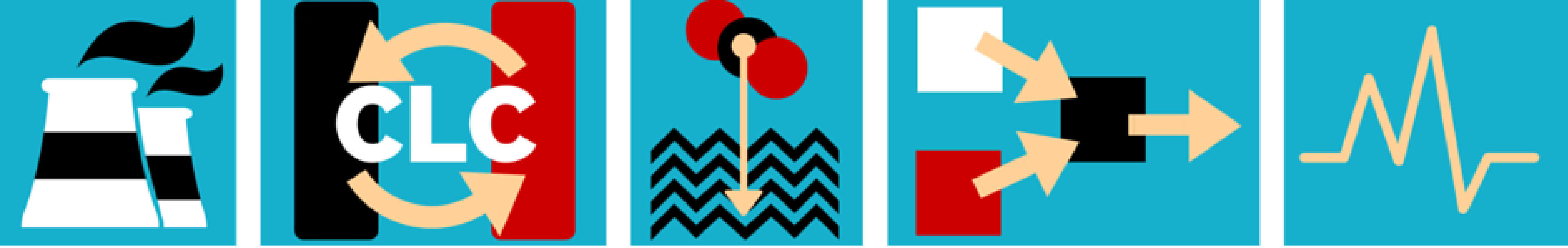

Dynamic Flowsheet Simulation of Gas and Solids Flows in a System of Coupled Fluidized Bed Reactors for Chemical Looping Combustion

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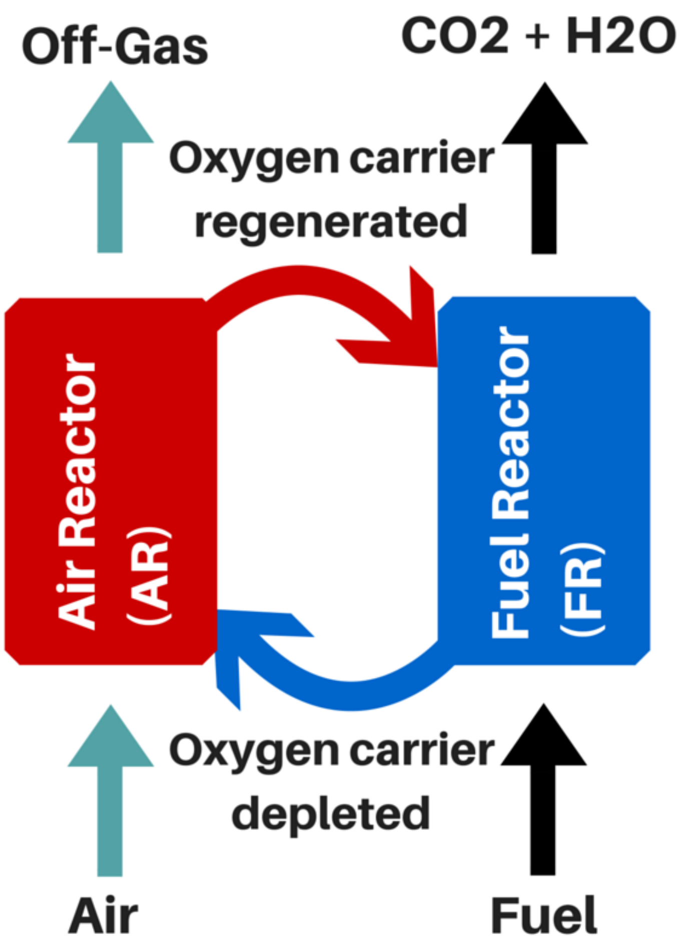
Dyn-Sim-FP
DYNAMISCHE SIMULATION
VERNETZTER FESTSTOFFPROZESSE
SPP 1679

Process specifics

- coupled fluidized bed reactors (bubbling, circulating)
- gas-solid separation via cyclones
- preventing gas mixing via loop seals

Earlier work in Chemical Looping at Hamburg University of Technology:

- steady state process simulation
  (Kramp et al., Fluidization XIV, 2013)
- combustion of lignite and ilmenite carrier
  (Thon et al., Applied Energy 118, 2014)
- combustion of lignite and bituminous coal and CuO carrier
  (Haus et al., Energy Technology, 2016)



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Challenges

- renewables as intermittend energy sources
- fossil fuel power stations at part load operation
- fast load changes

➢ Need for dynamic simulation of the CLC process

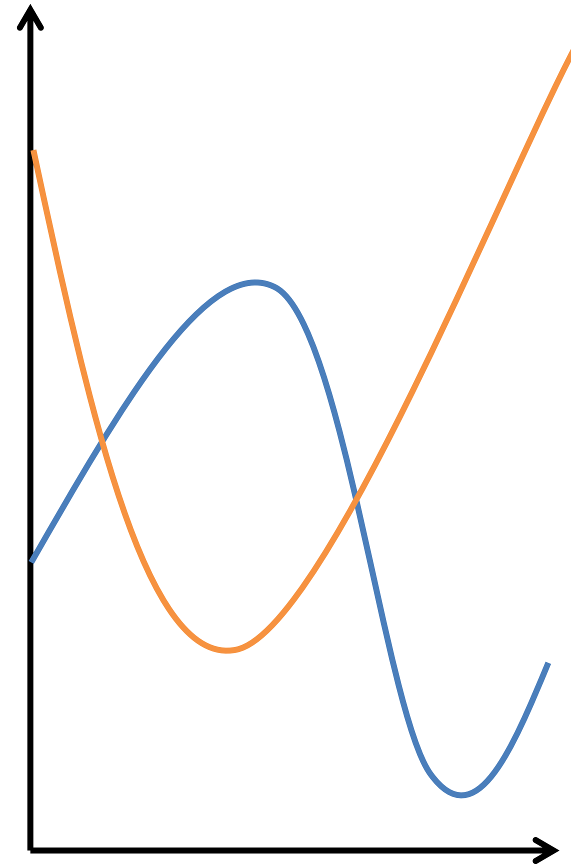
Method: dynamic flowsheet simulation of interconnected fluidized bed reactors

- **load changes**
- **start-up and shut-down** behavior
- **long-term effects** (attrition)

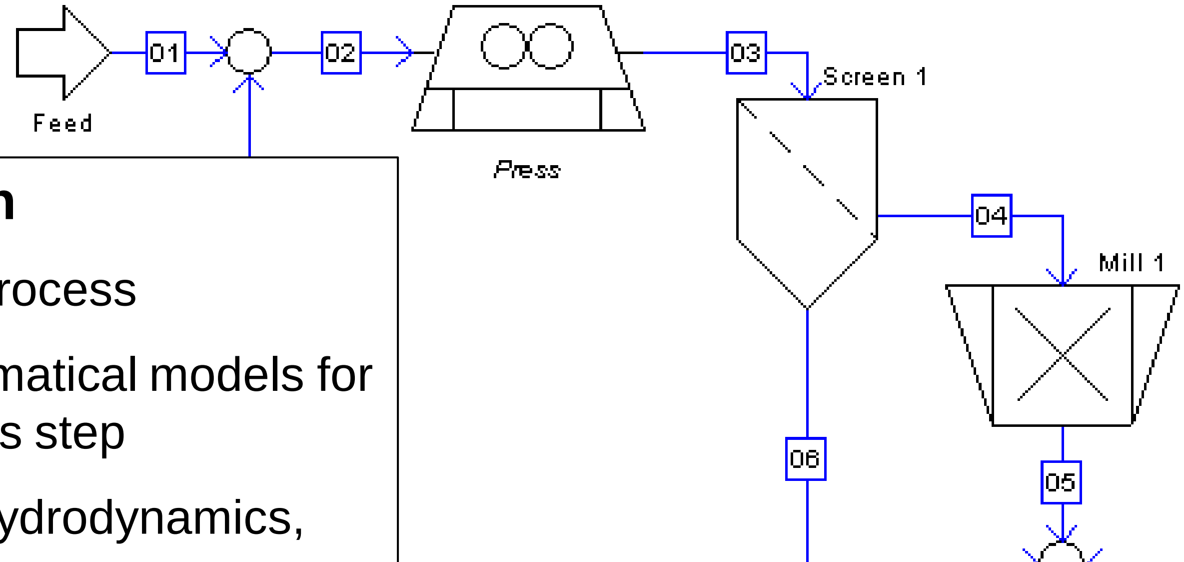
First approach for **dynamic** simulation:

- interconnection of fluidized bed reactors
- gas and solid flows
- **fluid mechanics** inside the coupled system

mass flows [kg/s]
bed mass [kg]
solids vol. concentration [-]
…



Flowsheet simulation of solids processes



Flowsheet simulation

- complete production process
- interconnected mathematical models for each individual process step
- simplistic models for hydrodynamics, chemical reactions etc.
- connected to a network by streams
- numerical solution

➢ fast calculation ($t_{simulation}$ > 1000s)

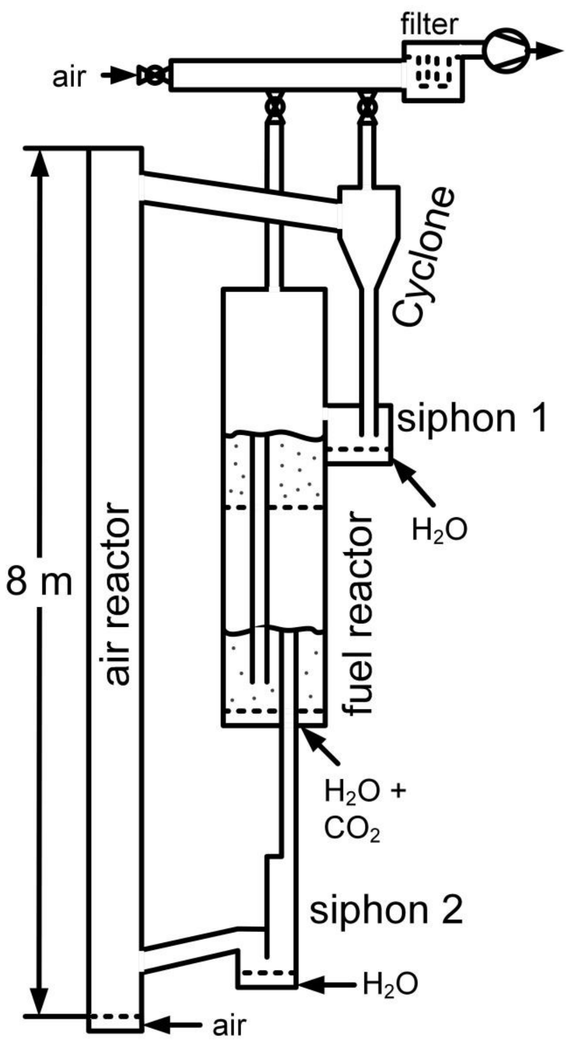
➢ for fluid processes "state-of-the-art"

➢ **solids processes more difficult because of distributed parameters**

DYSSOL (novel flowsheet environment)

- **dynamic simulation**
- distributed solids parameters

core system developed at Hamburg University of Technology



Experimental hot plant

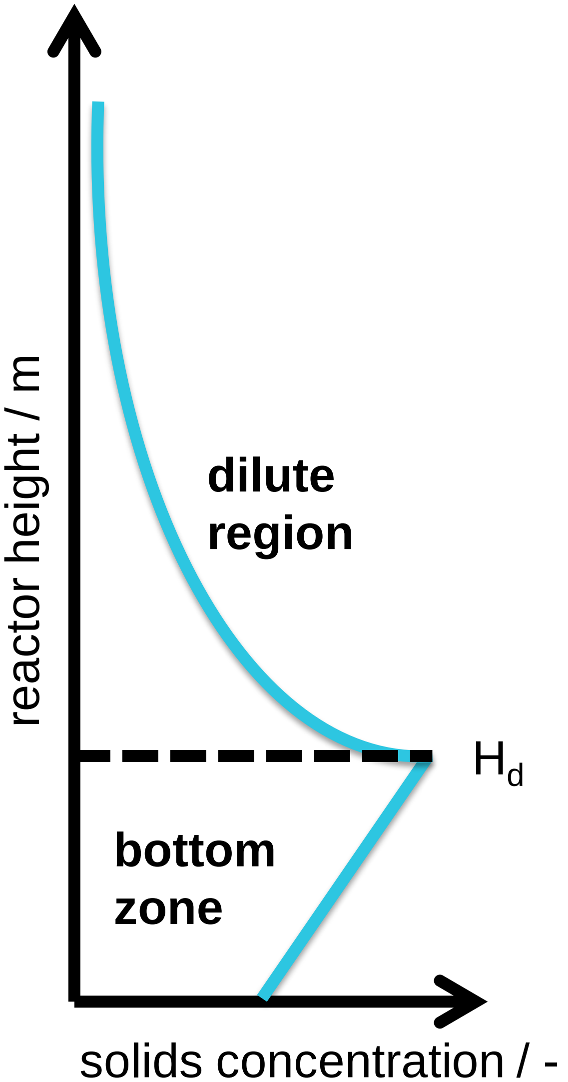
- combustion of solid fuels
- gas measurements
- pressure measurements

Dimensions

air reactor	8 m
fuel reactor	4 m
bed height FR	0.6 m
cyclone	0.34 m
siphon S1	0.16 x 0.13 m
siphon S2	0.13 x 0.25 m

Operation mode

- air reactor/ CFB riser (4 - 6 m/s)
- fuel reactor/ bubbling bed (0.15 - 0.30 m/s)
- siphons/ bubbling bed (0.10 - 0.30 m/s)



Fluidized bed reactor hydrodynamics

- dynamic unit (mass changes over time)

$$\frac{dm_{bed}}{dt} = \dot{m}_{in} - \dot{m}_{out}$$

Reactor is divided into dense bottom zone and dilute upper region (Werther and Hartge, 2003):

- solids vol. concentration in bottom zone via two-phase model, bubbles and suspension (Werther and Wein, 1994)
- exponential decay of solids concentration in upper region (Kunii and Levenspiel, 1991):

$$c_{v,i}(h) = c_{v\infty,i} + \left(c_{v,i}\left(h_{bed}\right) - c_{v\infty,i}\right) \cdot \exp\left(-a \cdot (h - h_{bed})\right)$$

- Reactor mass given by:

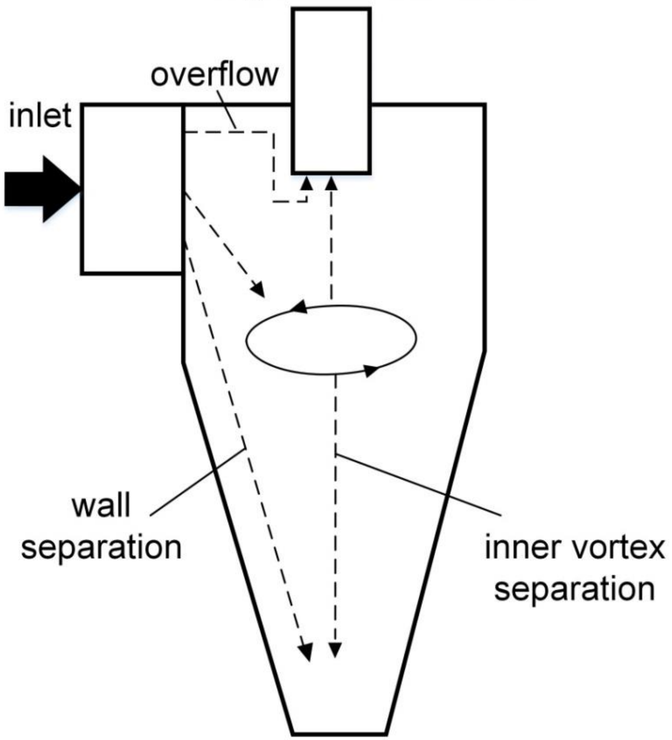
$$m_r = \rho_s \cdot \left\{ \int_0^{H_d} \bar{c}_v(h) \cdot A_t \, dh + \int_{H_d}^{H_r} \bar{c}_v(h) \cdot A_t \, dh \right\}$$

Flowsheet Modeling Approach

Cyclone and loop seal modeling

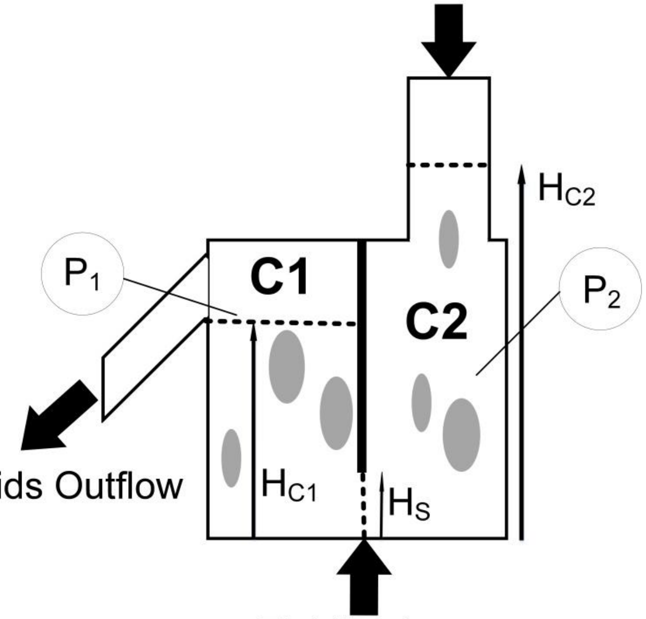
Cyclone modeling

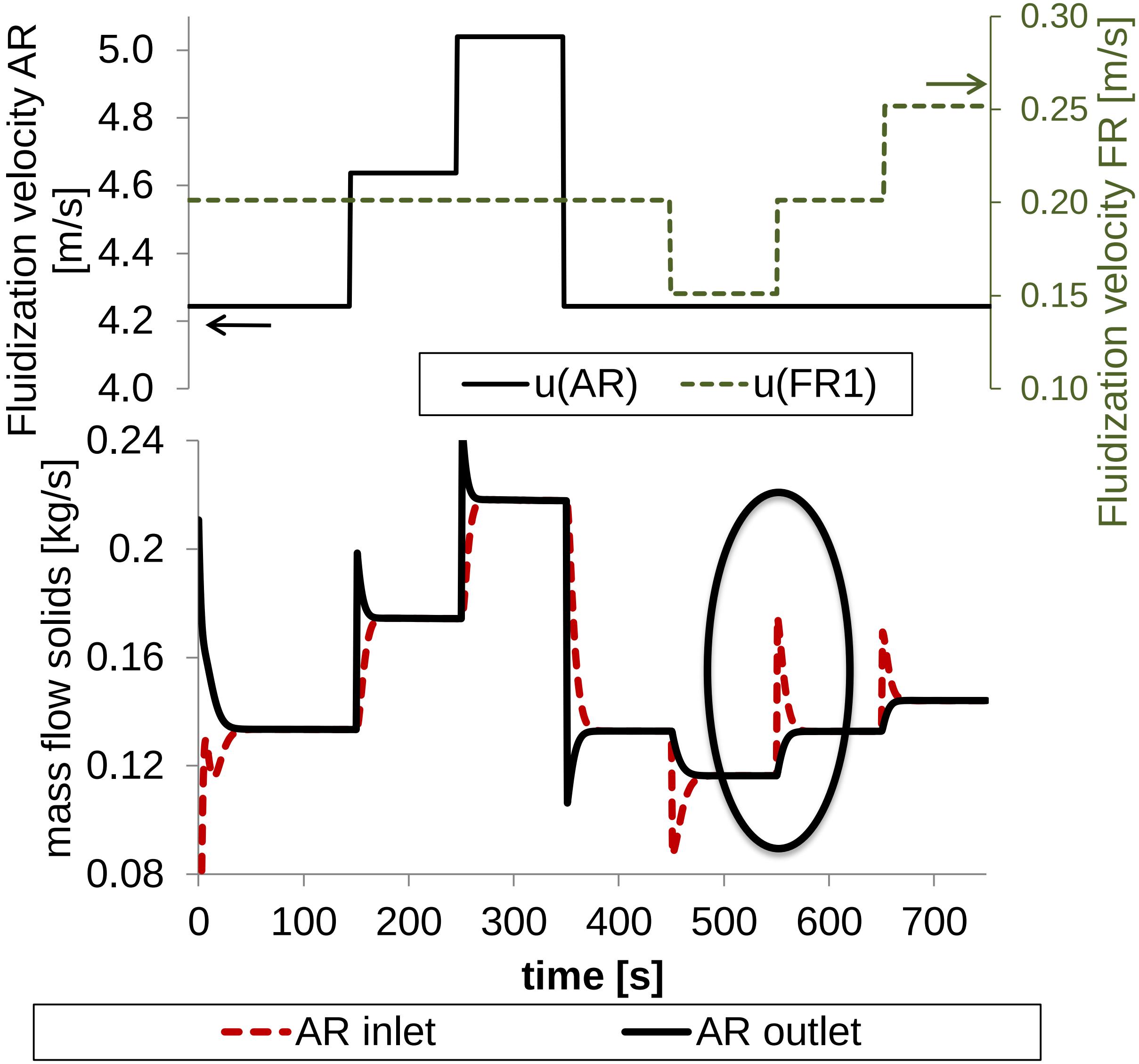
- according to Muschelknautz in VDI Heat Atlas 2007
- steady state model



Loop seal modeling (dynamic)

- modeled as siphons with 2 bubbling bed chambers
- unlimited solids flow through siphon
- dynamic model





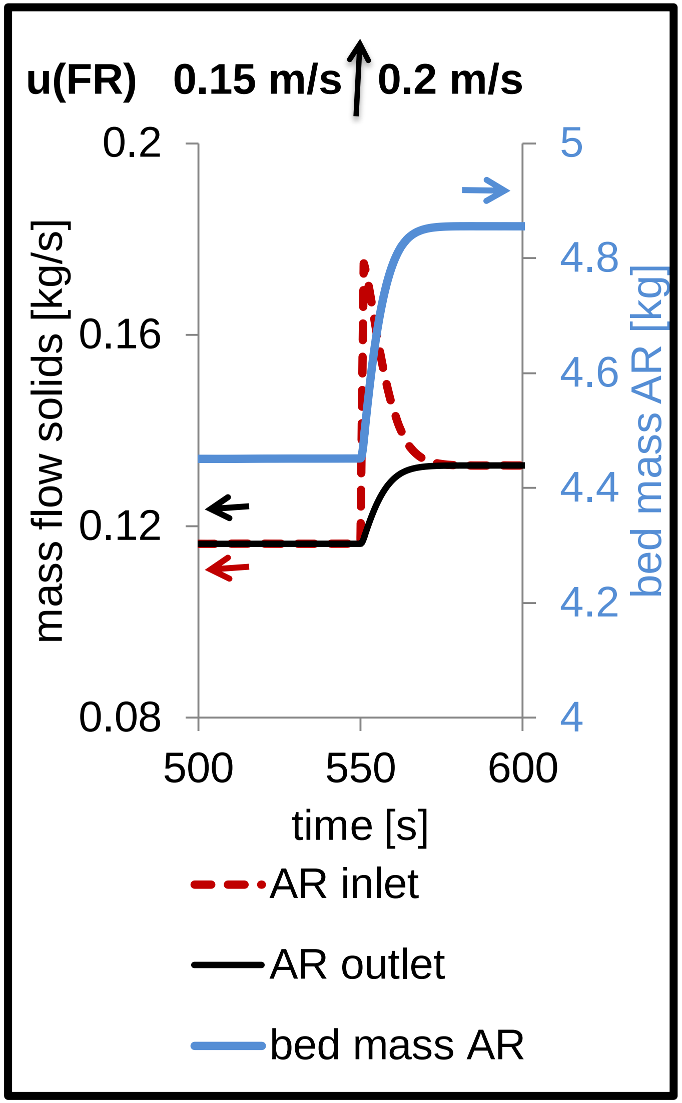
Simulation and experimental setup

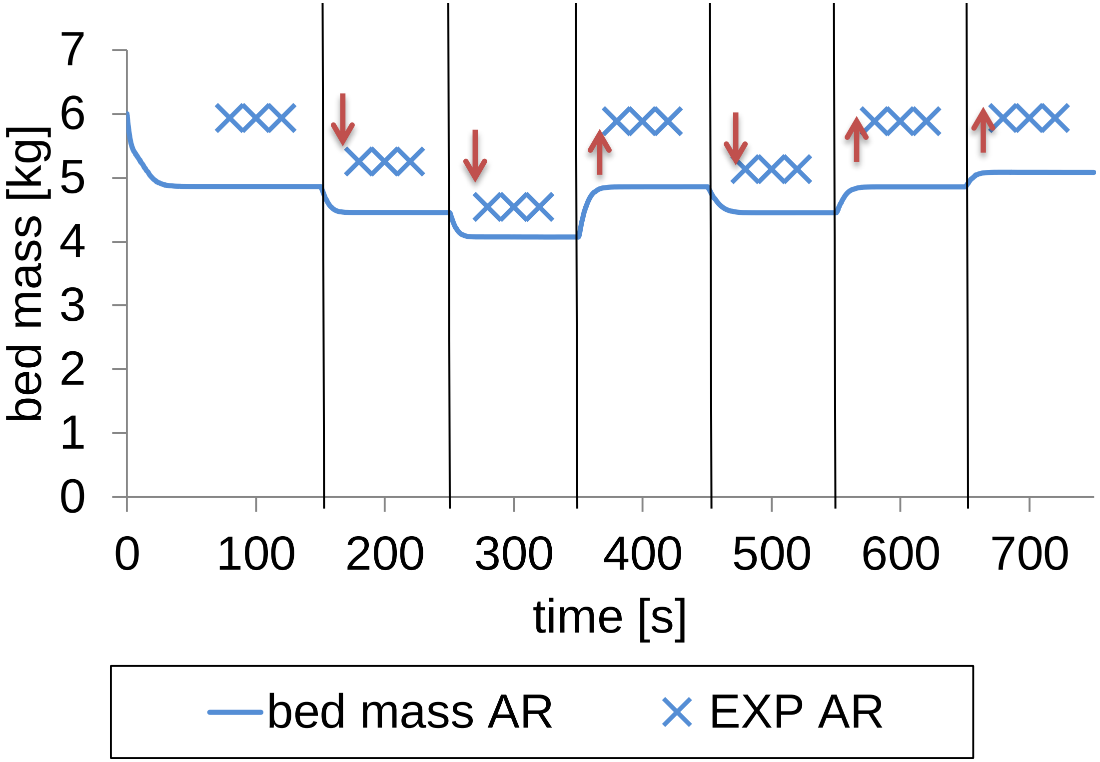
- Dynamic effects investigated
- Experiments and simulation closely linked for validation

Influence on mass flows in the system

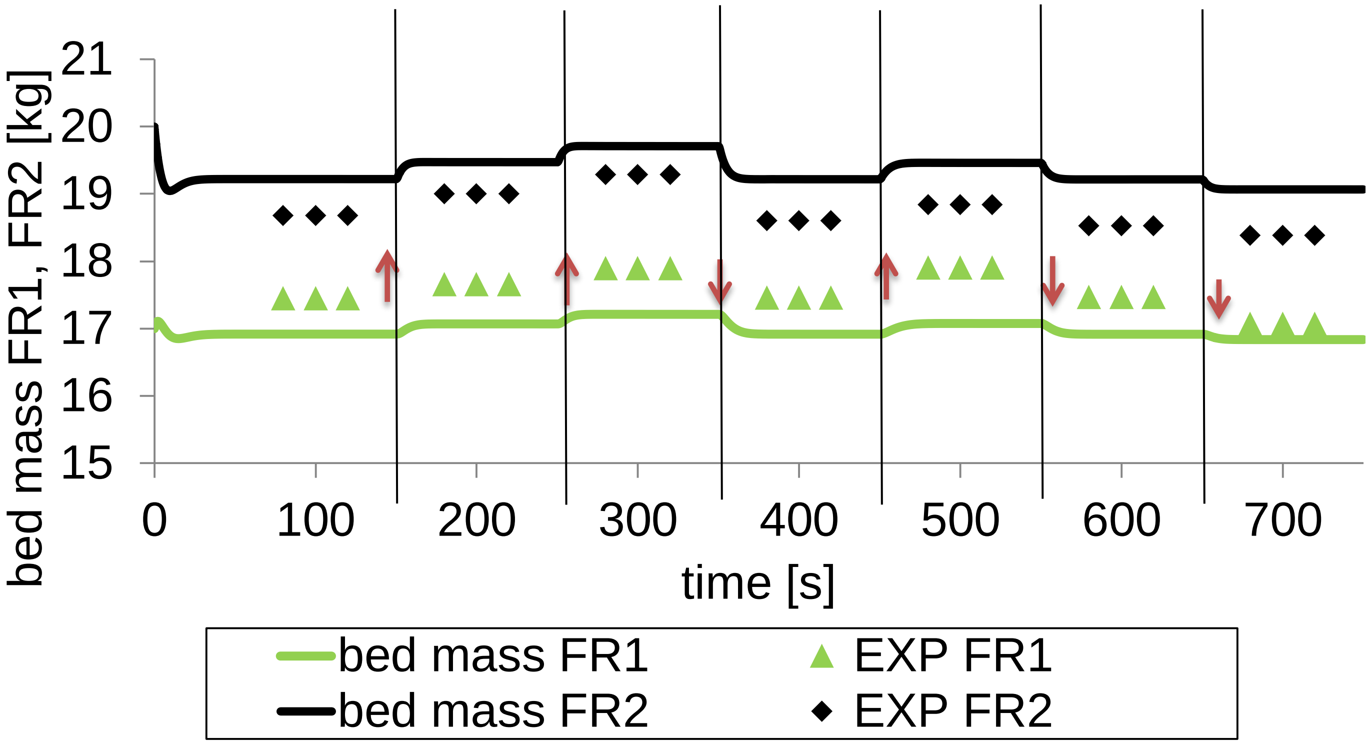
- fluidization u (AR)↑ solids circulation↑
- fluidization u (FR)↑ solids circulation↑
- experimental circulation: 0.13 - 0.36 kg/s
- simulated circulation: 0.1 - 0.22 kg/s

Mass flows and bed masses in the system

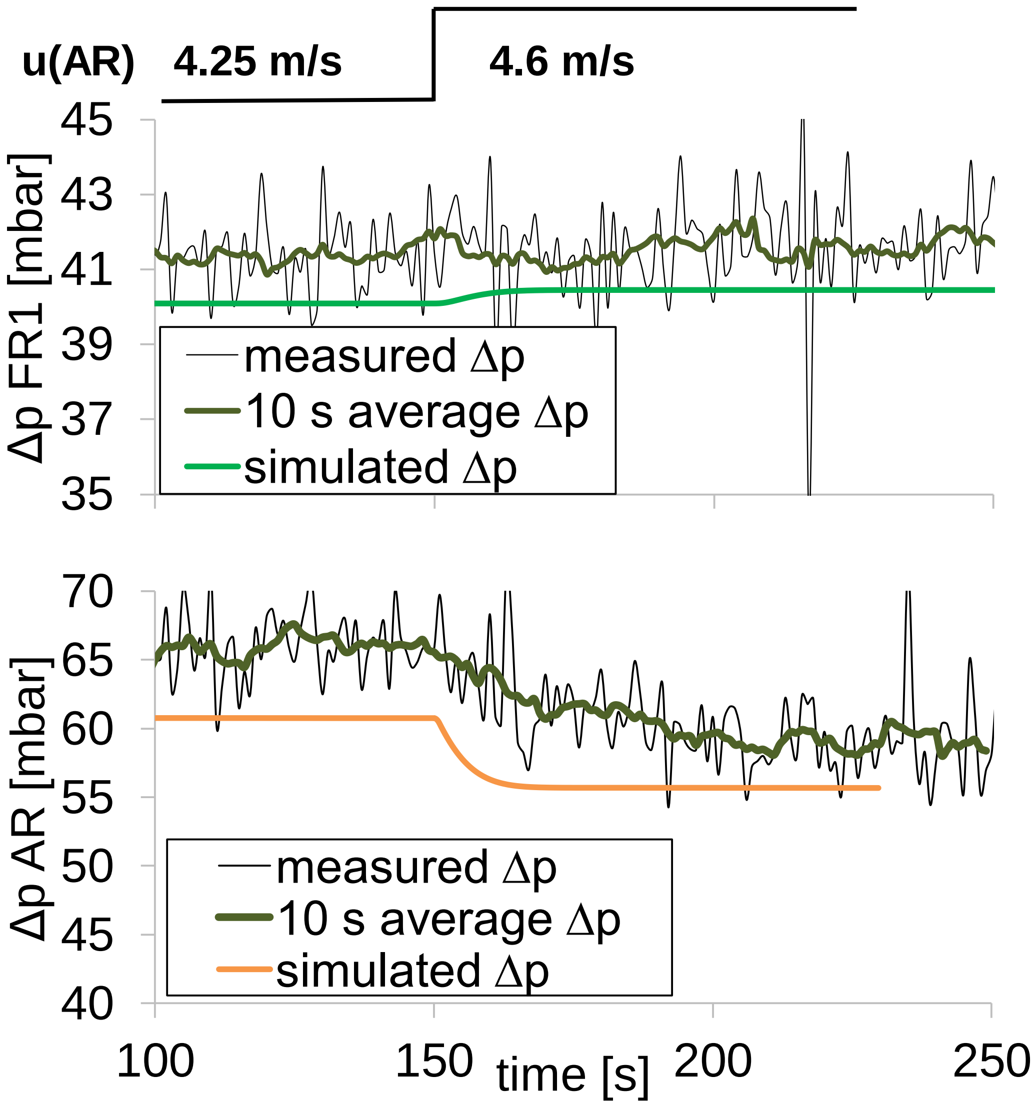




- fluidization u (AR) ↑
  bed mass AR ↓
- fluidization u (FR) ↑
  bed mass AR ↑



- bed masses in FR1 and FR2 captured (within 5 w-%)
- AR bed mass underpredicted by model by 15-20 w-% (bed mass from pressure measurements)
- dynamic changes described in simulations correctly in size and direction



Dynamic effects

- air reactor dynamics described in experiments and simulation
- difficulties in FR: pressure fluctuations large compared to overall pressure change

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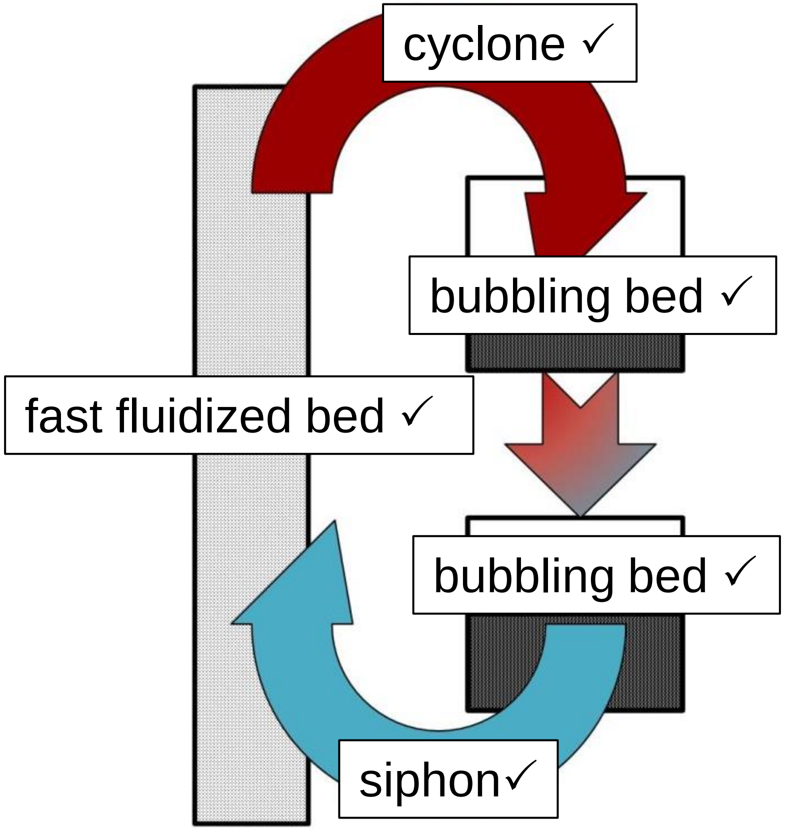
Summary

- solids flow/fluid dynamics simulated
- solids parameter taken into account (PSD)
- 4 process units implemented
- dynamic changes captured
- modeling improves understanding of the coupled system



Next steps for process simulation

- reaction kinetics (combustion, gasification)
- pressure coupling
- models improvement (fluidized bed, siphons)
- attrition

Thank you for your attention and see you at my poster for further discussions!

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