Institute for Energy Systems
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Detailed CFD-DEM Simulation of Biomass Gasification in a Fluidized Bed Reactor

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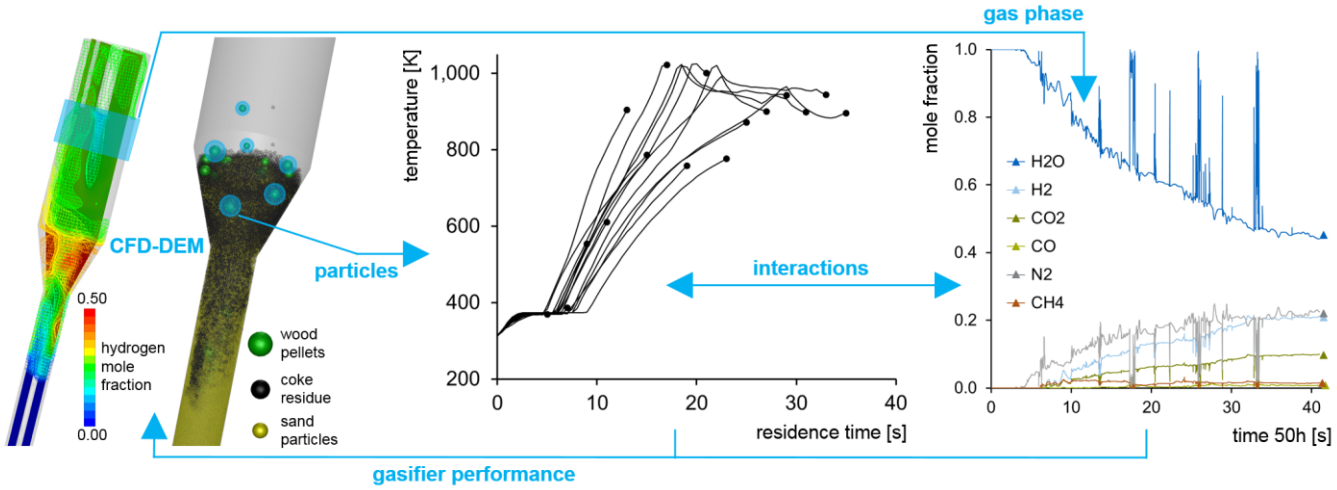

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FLUIDIZATION XVI

May 26 – 31, 2019

AGENDA

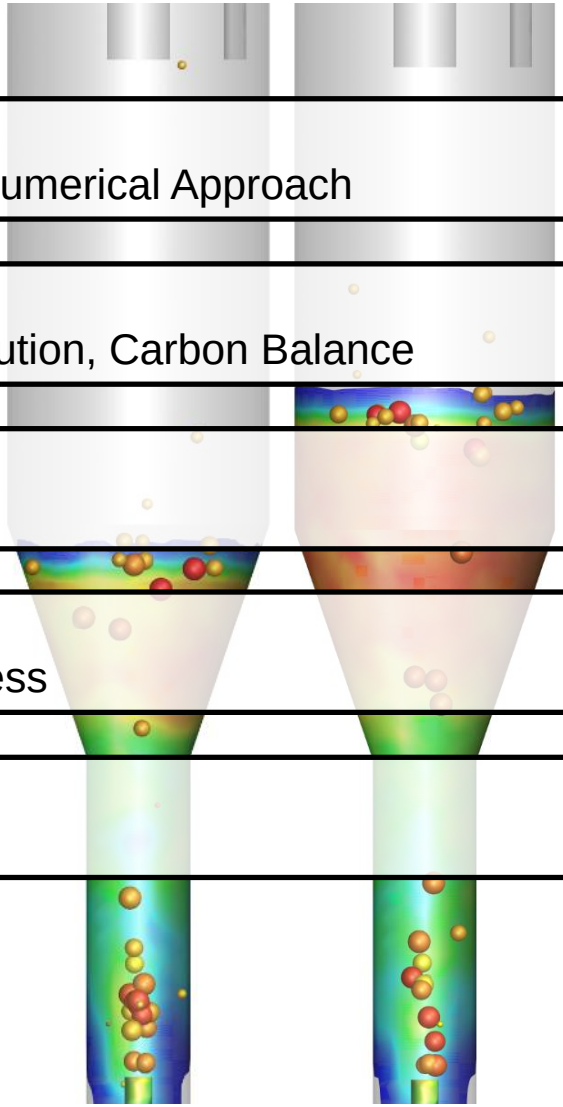
SIMULATION SETUP
Geometry, Material, Initial and Boundary Conditions, Numerical Approach

GASIFIER PERFORMANCE
Pressure Drop, Gas Composition, Temperature Distribution, Carbon Balance

BIOMASS PELLET EVOLUTION
Conversion and Heating Rate

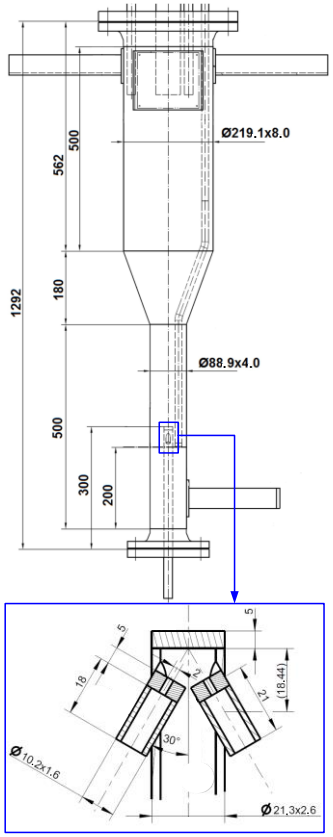
FLUIDIZATION BEHAVIOR
Hydrodynamics and Coupling to the Gasification Process

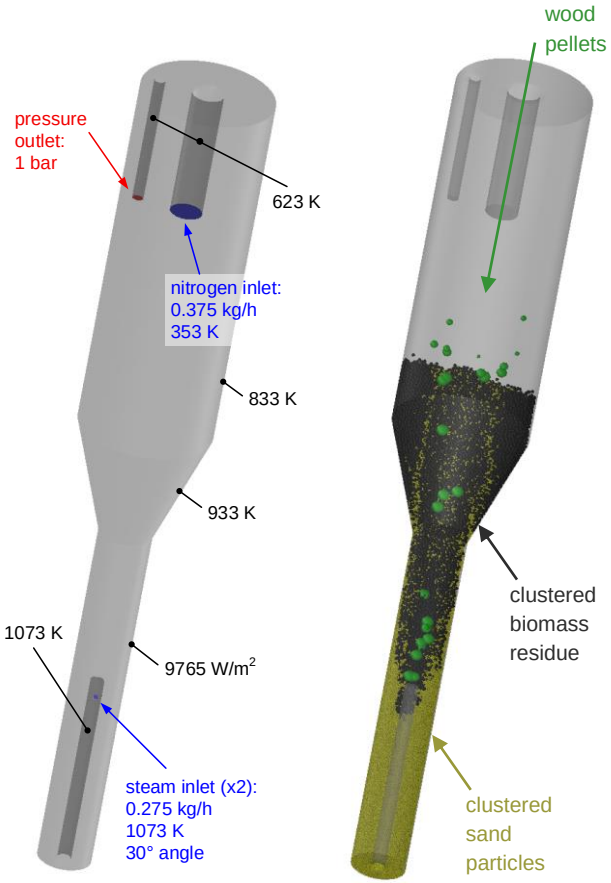
CONCLUSIONS
Summary and Outlook

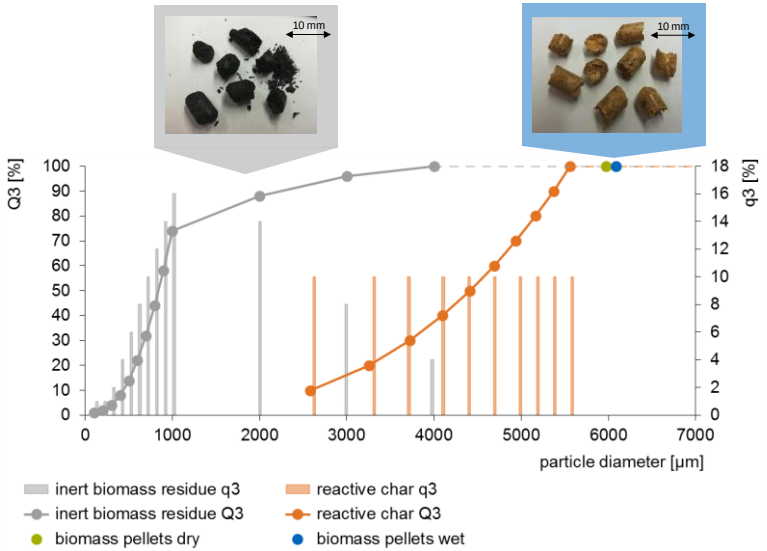


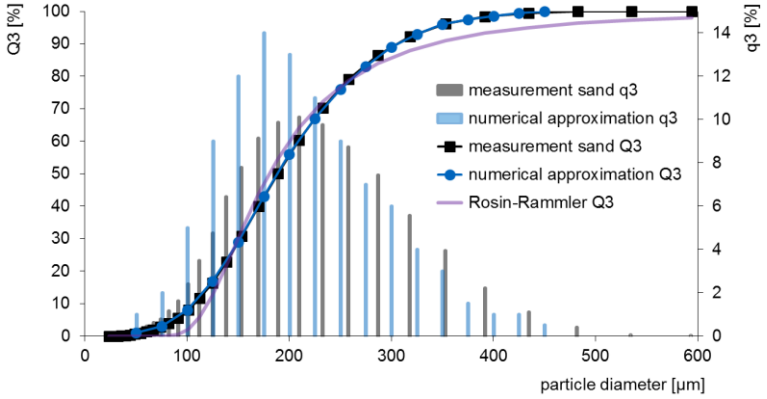
SIMULATION SETUP

Geometry, Material, Boundary Conditions









Geometry of the gasification reactor with detailed view of the inlet nozzles in mm (left), boundary conditions (middle), and computational grid of the reactor (right).

Particle size distribution of the inert residue, the reactive char, the wet and dry wood pellets (top), and of the inert sand (bottom).

SIMULATION SETUP

Initial Conditions, Numerical Approach

33 000 computational cells

150 000 sand parcels
50 000 residue parcels
40 wood pellets

Fluid time step size: 0.5 ms
Particle time step size : 0.05 ms

Interaction: **CFD-DEM**
(4-way-coupling)

Hydrodynamics: laminar / turbulent (k-ε)

Heat transfer: Ranz-Marshall / Gunn

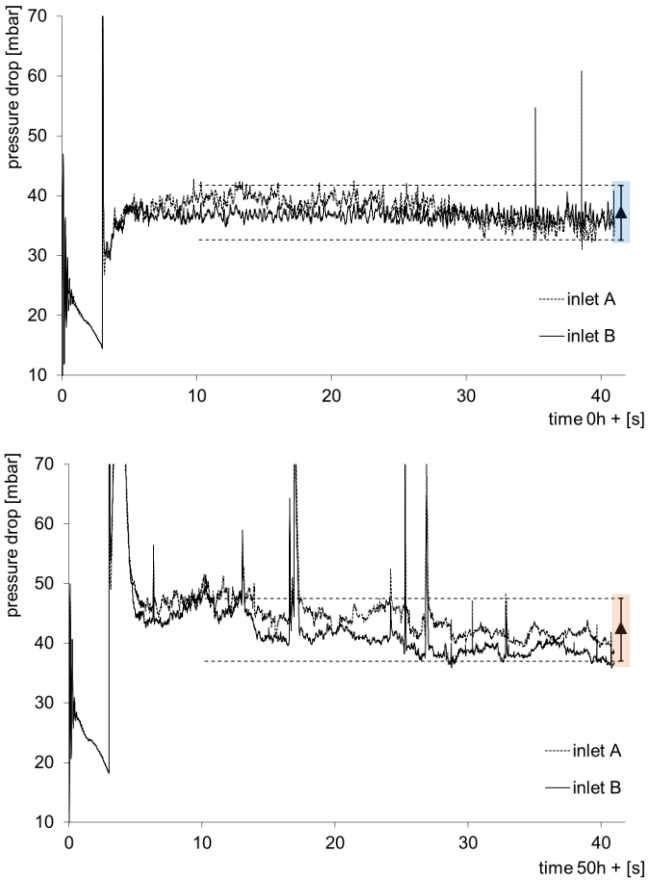
Kinetics: simplified (5 reactions)

Fluidization behavior of inert sand particles (yellow), inert residue (black), and reactive wood pellets (green) for the start-up process/0h (left), after 20h (middle), and after 50h (right) operational time.
Explanatory note: 100% on the left hand side means that all solids in the reactor are displayed, whereas 50% on the right hand side means that only the 50% of the sand and the residue in the rear half of the reactor are displayed. In each case, all the wood pellets are displayed. The image sampling rate is 2 Hz.

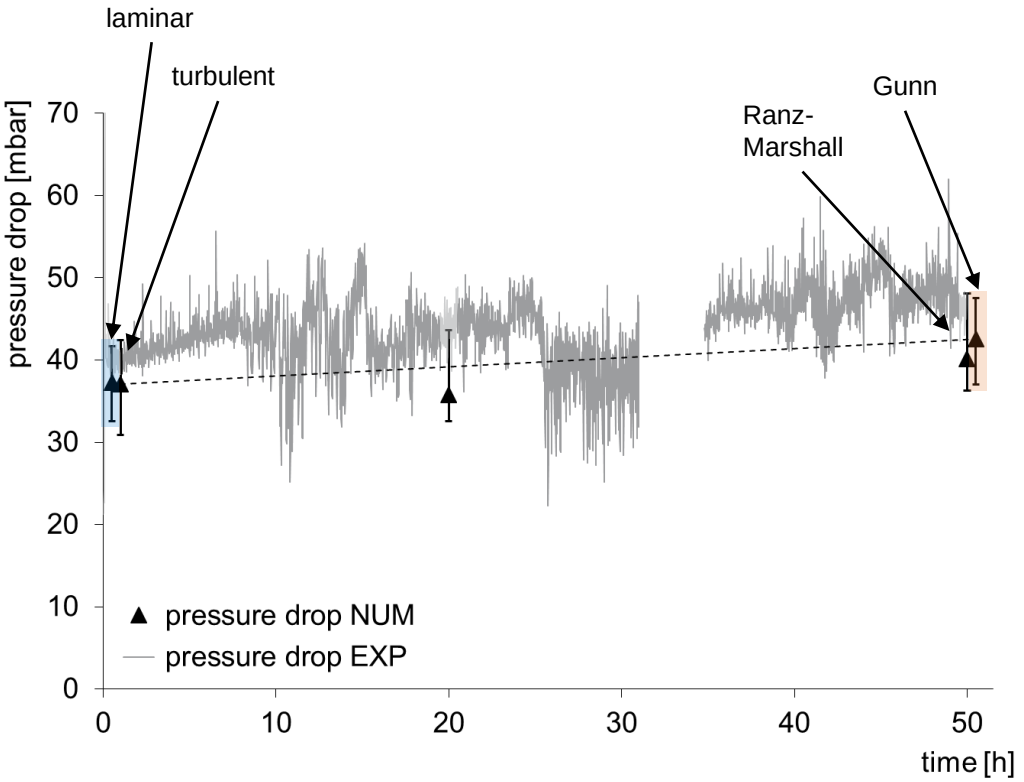
0-3 s: settling of particles
3-6 s: start fluidization (steam)
6-41 s: feed/patch biomass pellets

GASIFIER PERFORMANCE

Pressure Drop



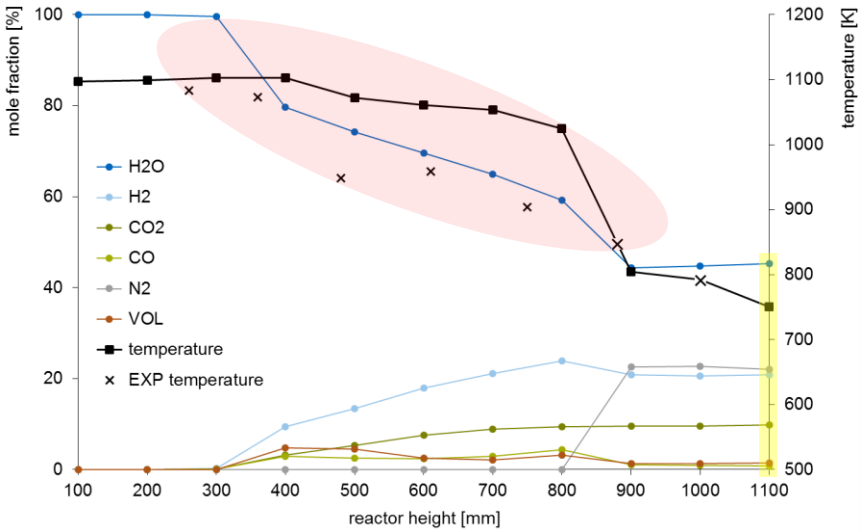
Numerical pressure drop for the start-up process (top) and after 50 h operational time (bottom).



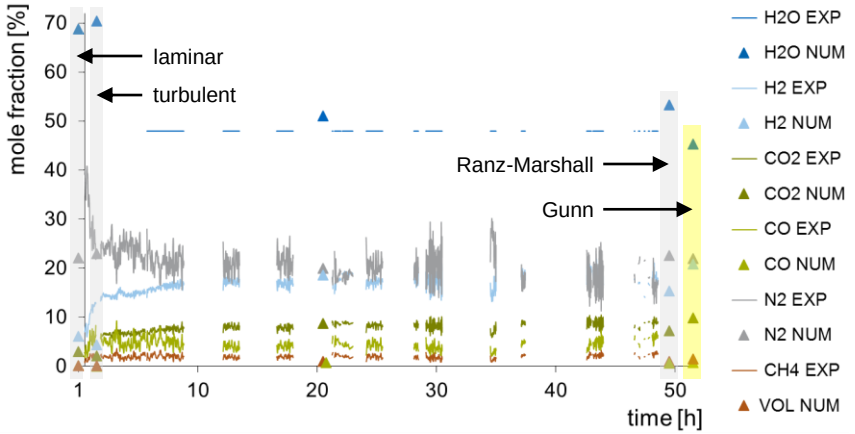
Comparison to experimental data.

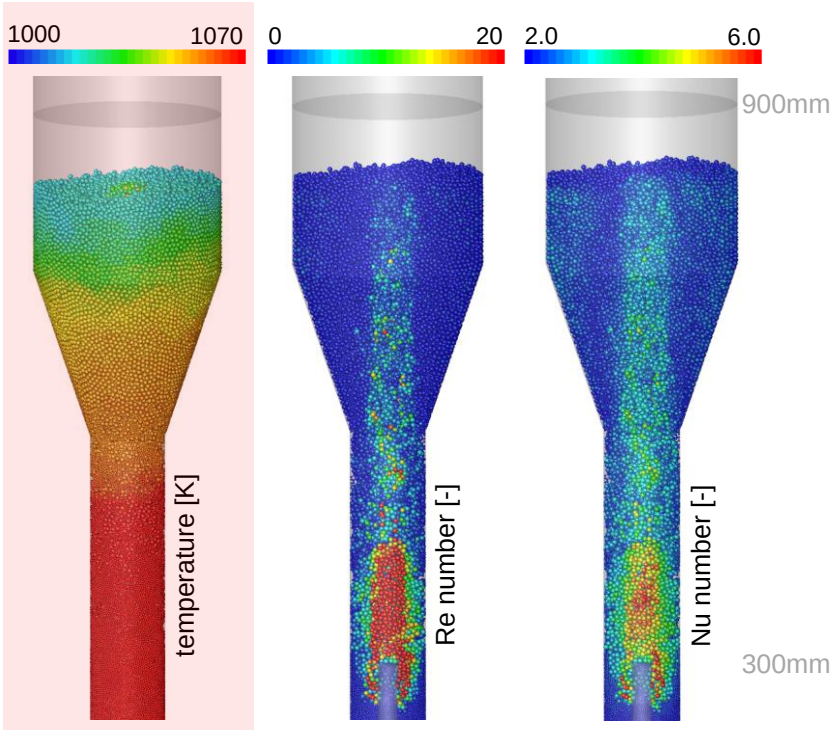
GASIFIER PERFORMANCE

Gas Composition and Temperature Distribution



Cross-sectional-averaged numerical gas compositions, as well as experimental and numerical temperatures over the gasifier height.



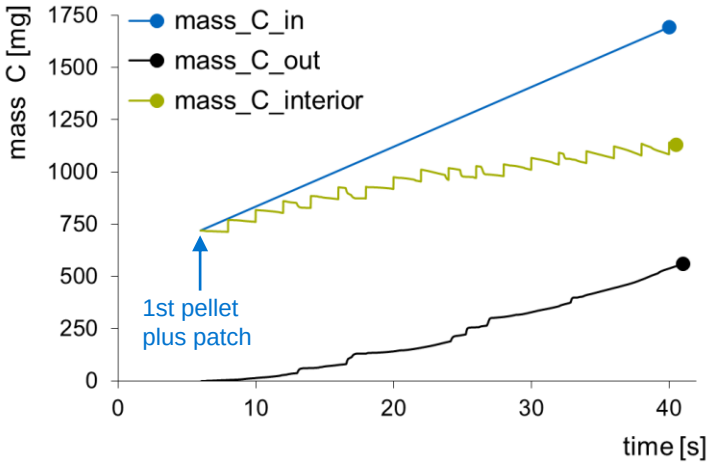


Particle temperature (left), as well as Re numbers (middle) and Nu numbers (right) after 41 seconds of simulation and a previous operating time of 50 hours.

Numerical (symbols) and experimental (solid lines) product gas composition for different operating times.

GASIFIER PERFORMANCE

Carbon Balance



$$\frac{dC_{in}}{dt} = 29\,\mathrm{mg/s}$$

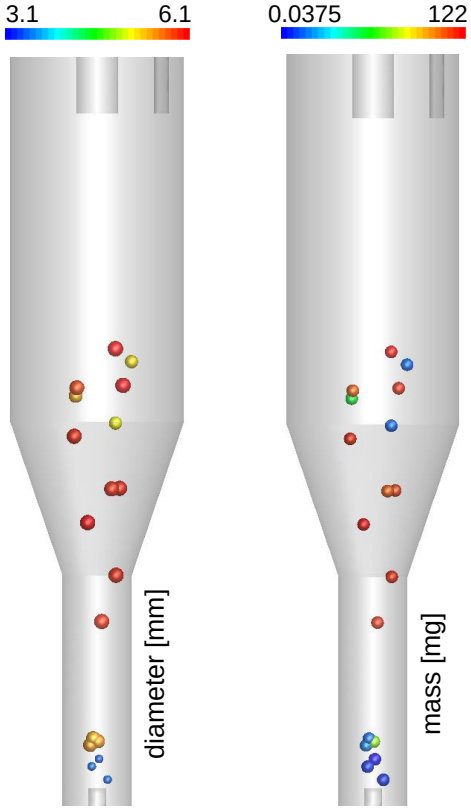
$$\frac{dC_{out}}{dt} = 23\,\mathrm{mg/s}$$

Mass of carbon into (blue) and out of the gasifier (black) and its accumulation inside (green) at 50 h.
Heat transfer: Gunn.

Ranz-Marshall 50h ↓ Gunn 50h ↓

Carbon conversion numerical: 61 % / 78 %

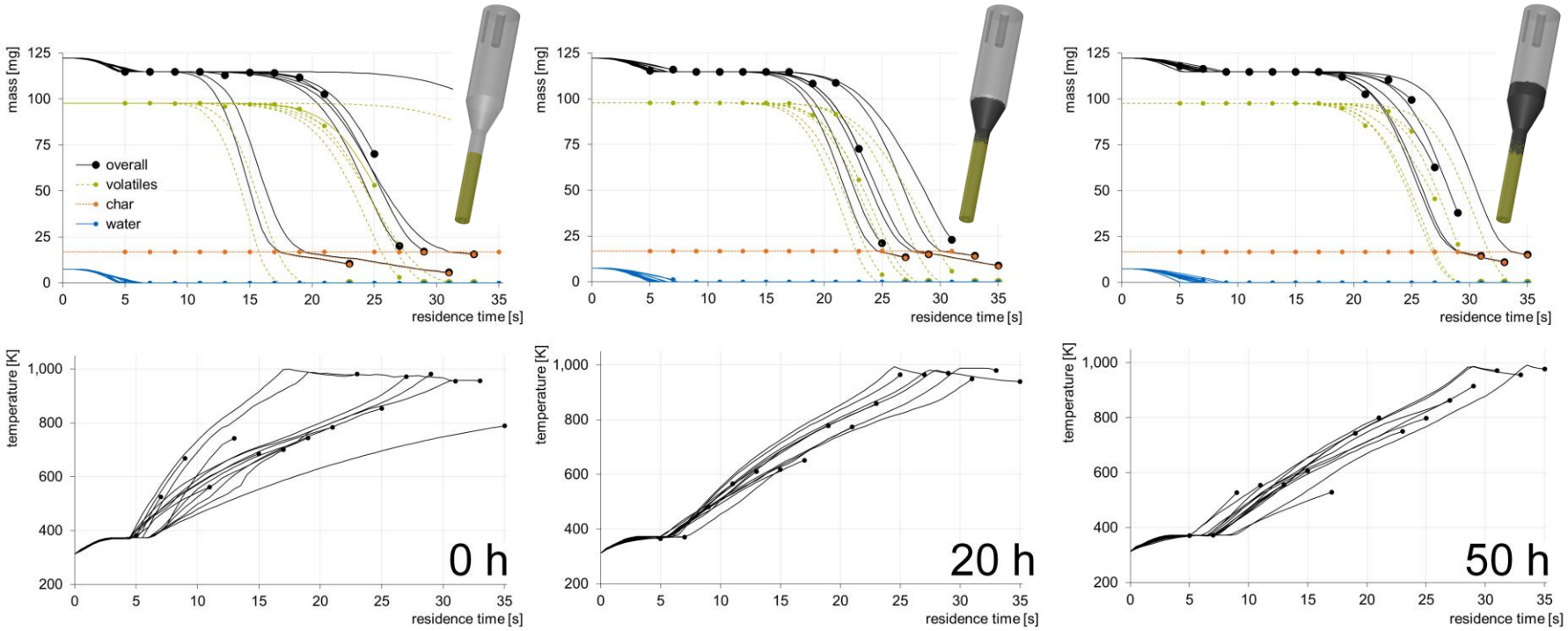
Carbon conversion experimental: 80-85 %



Diameter (left) and mass (right) of the wood pellets after 41 seconds of simulation at 50 h.
Heat transfer: Gunn.

BIOMASS PELLET EVOLUTION

Conversion and Heating Rate

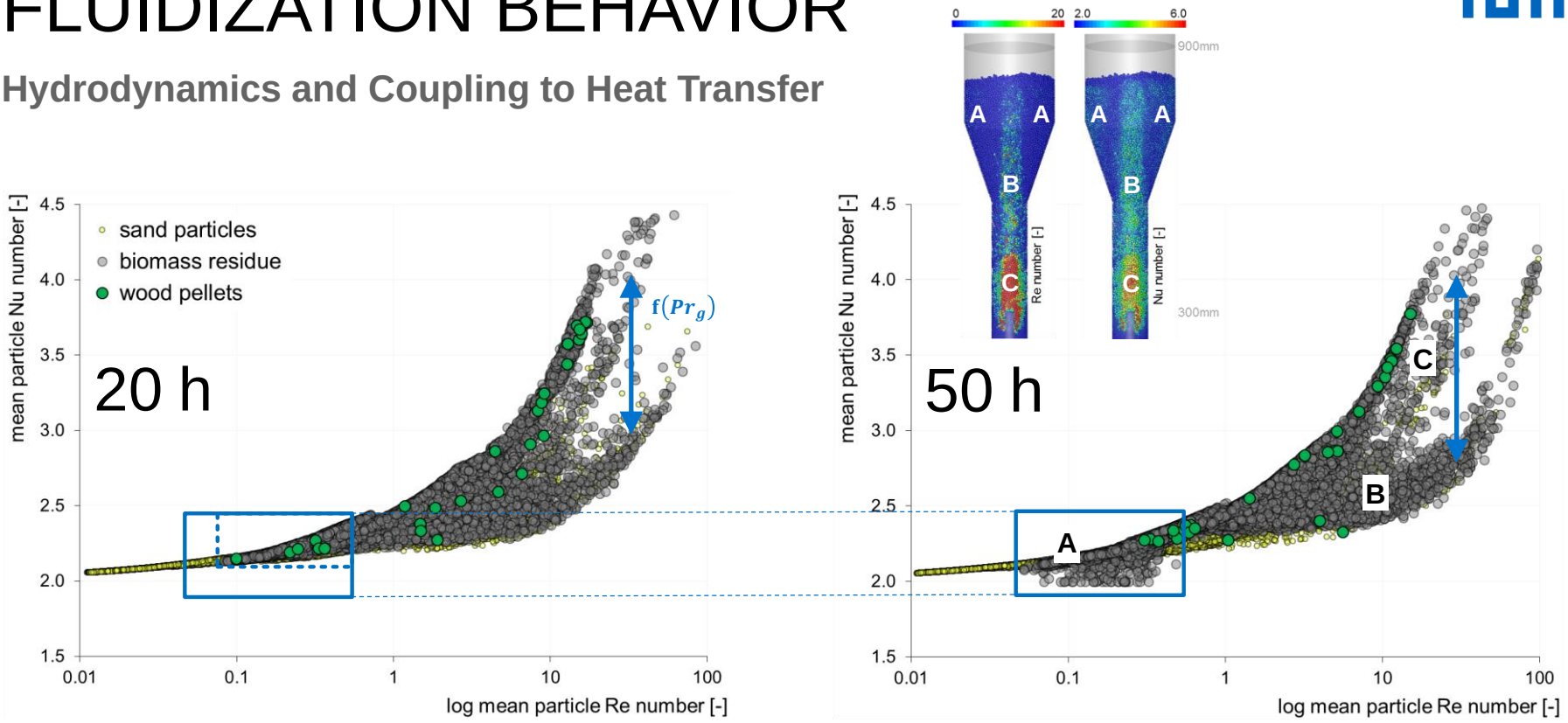


Evolution of composition (top) and temperature (bottom) of the biomass pellets injected between 6 and 36 seconds (residence times of at least 5 seconds). *Heat transfer: Ranz-Marshall.*

Average heating rates: **29 K/s** (0 h), **26 K/s** (20 h), **24 K/s** (50 h)
42 K/s (50 h *Gunn*)

FLUIDIZATION BEHAVIOR

Hydrodynamics and Coupling to Heat Transfer



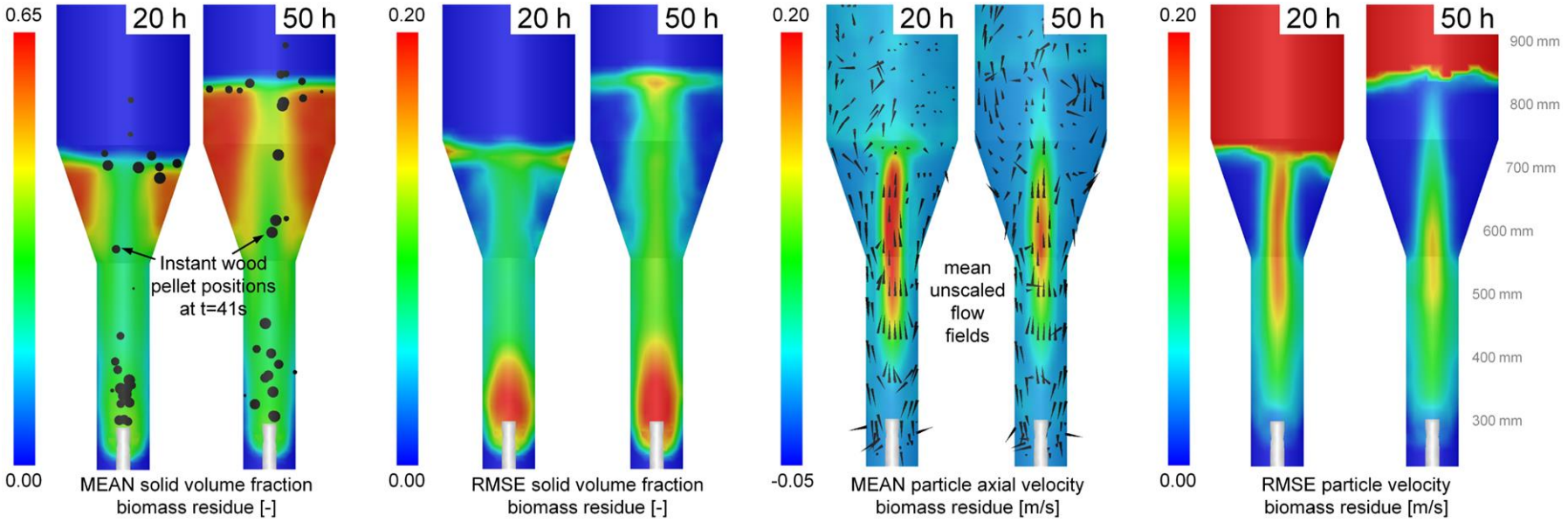
Mean particle Nu numbers of sand (yellow), biomass residue (gray), and wood pellets (green) over mean particle Re numbers (averaged over 35 seconds). *Heat transfer: Ranz-Marshall.*

Average Re numbers wood pellets: **6.82** (20 h), **4.48** (50 h)
Average Nu numbers wood pellets : **2.87** (20 h), **2.75** (50 h)

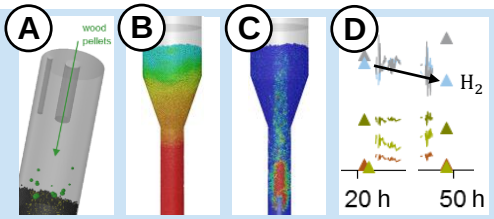
Improved mixing behavior and heat transfer in lower bed area → faster pellet conversion
Deteriorated mixing behavior and heat transfer over time → slower pellet conversion

FLUIDIZATION BEHAVIOR

Hydrodynamics



MEAN solid volume fraction distribution with RMSE values (left) and MEAN particle axial velocity with RMSE values (right) of the biomass residue at the center plane of the gasifier (averaged over 35 seconds).



(A) Pellets are fed into the reactor in the freeboard region

(B) Thermal and material insulating residue layer forms over time

(C) Biomass heating and conversion is high in lower bed area

(D) Operating time ⇧ ⟶ residue layer ⇧ ⟶ pellet penetration ⇩ ⟶ gasifier performance ⇩

CONCLUSIONS

Summary

Reasonable prediction of gasifier performance

Model validation:

- pressure drop
- gas composition
- gas temperature
- pellet evolution (heating rate and conversion)
- solids distribution and movement

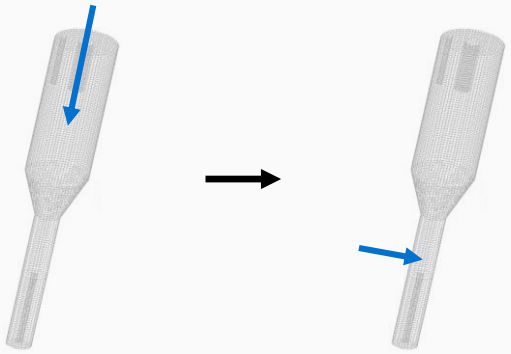
Investigation of:

- defluidization over time (residue accumulation)
- coupling between
  - hydrodynamics
  - heat transfer
  - gasifier performance

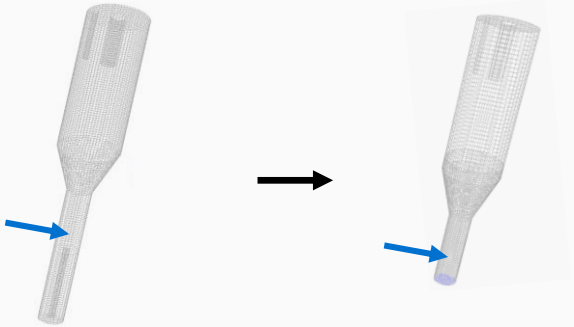
Outlook

Improvement of reactor operation and design:

- pellet feed in lower well-mixed area



- simplified reactor design to avoid channeling



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Thank you for your attention!
Questions?

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