RUHR-UNIVERSITÄT BOCHUM

Lehrstuhl für Energieanlagen und Energieprozesstechnik
Prof. Dr.-Ing. V. Scherer

DEM modelling of biomass packed bed combustion and link with CFD furnace models

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www.leat.rub.de

Overview:

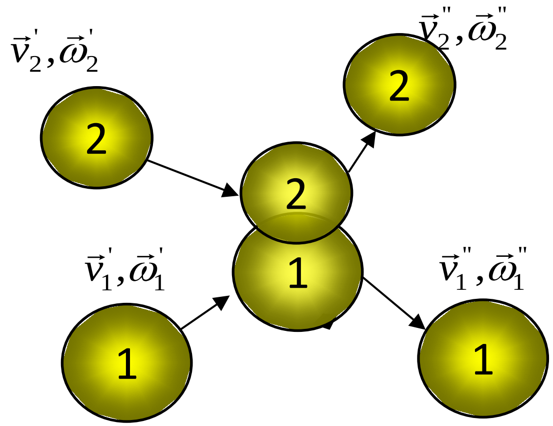
- Introduction
- The Diskrete Element Method
- Mechanical properties and behaviour
    - Static
    - Dynamic
- Heat transfer
    - Conduction and radiation
    - Convection
- Combustion
- Example of technical system: MSW incinerator

Combustion of solid biomass

Some obvious statements:

- water content, calorific value and „difficult“ mechanical properties
- intensive preparation is economically not feasible: „burnt as delivered“
- particles are large in comparison to conventional pulverized fuels
- particle shape is far from spherical, often unknown
- stoking of some kind (mechanical interaction) is required
- heating is strongly influenced by in particle heat conduction
- mechanical and thermochemical properties may vary from particle to particle
-
-

-> simulation based on a discrete representation is required

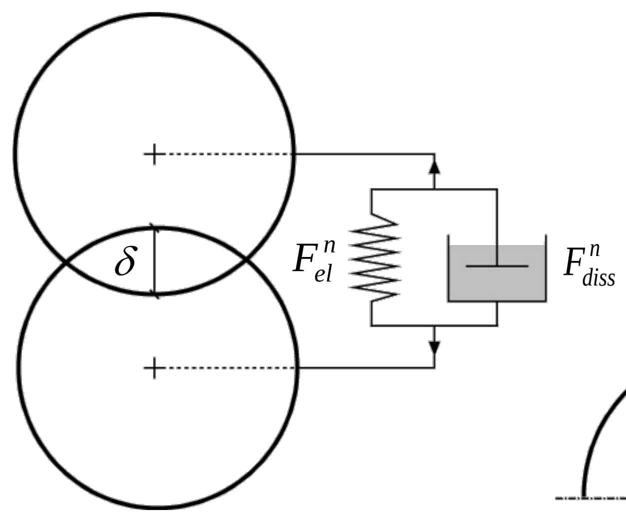


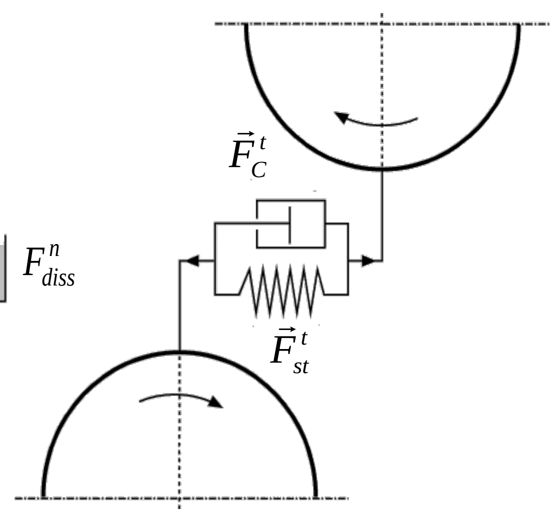
- solid particles
- multiple contacts (impacts)
- Beschreibung der Bewegung durch:
  - Newton (translational)

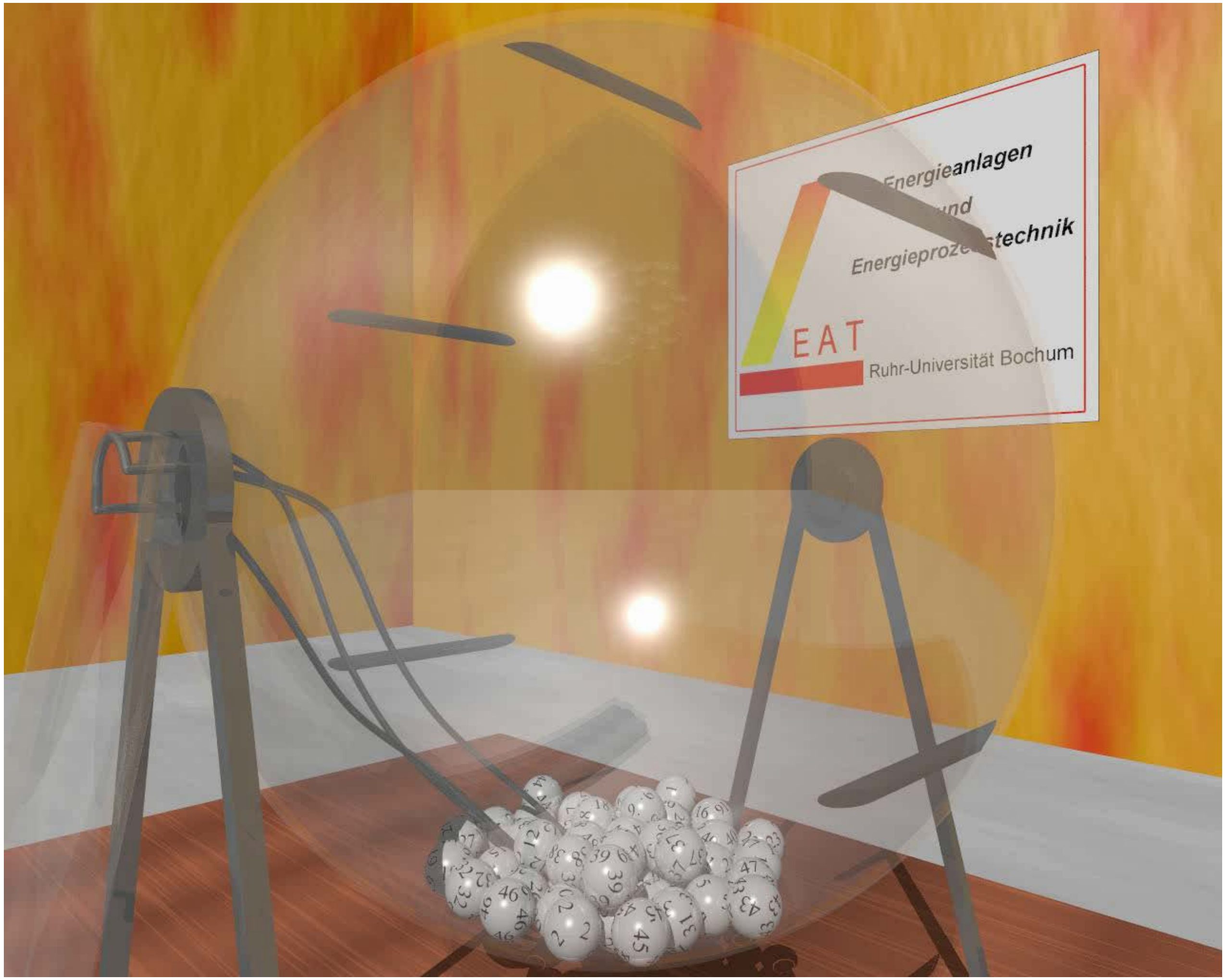
$$m_i \frac{d^2 \vec{x}_i}{dt^2} = m_i \vec{g} + \sum_{j=1}^{N} \vec{F}_{ij}$$

  - Euler (rotational)

$$I_i \frac{d^2 \vec{\varphi}_i}{dt^2} = \sum_{j=1}^{N} \vec{M}_{ij}$$



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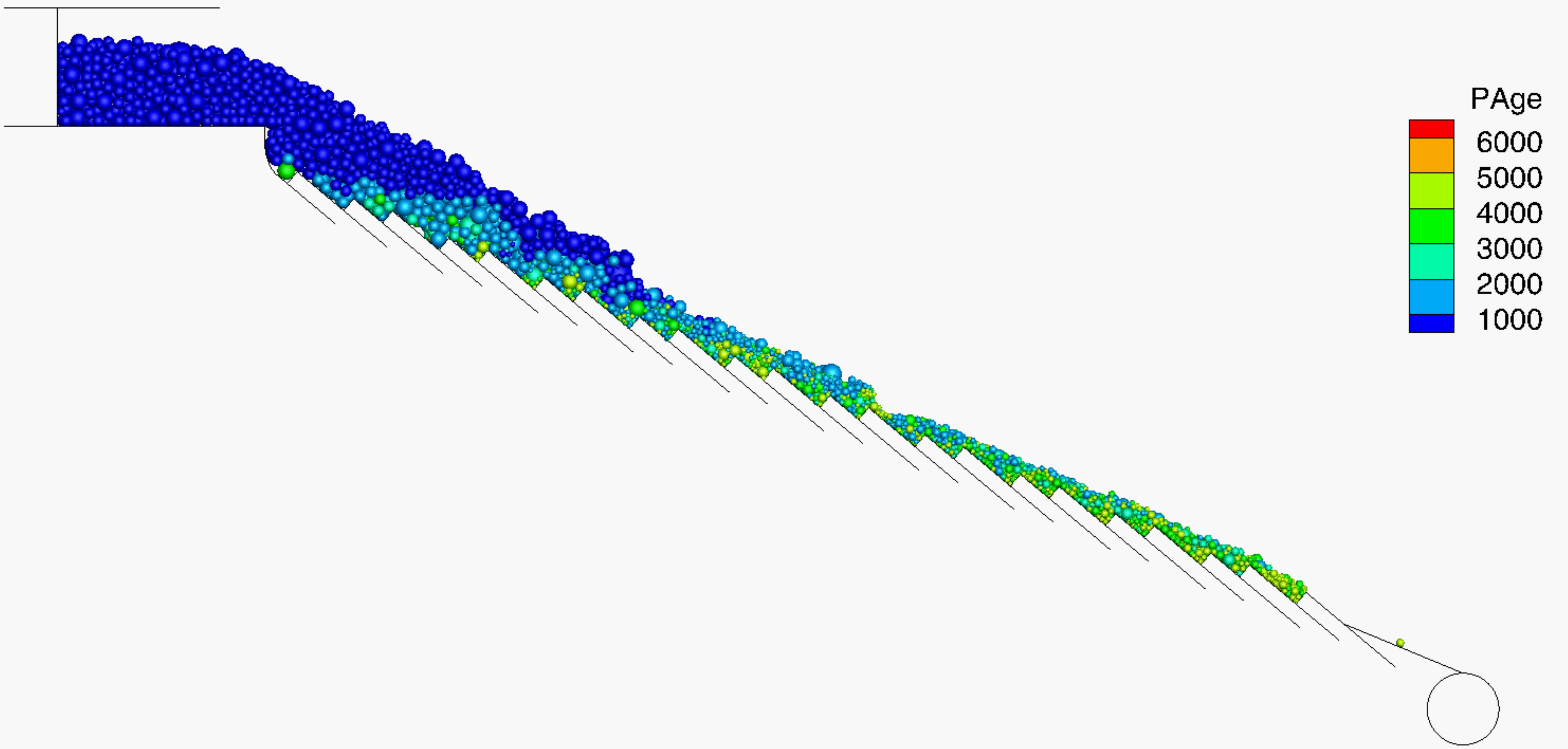
… move towards more realistic decriptions of the mechanical behaviour(dynamic/static)

1.) adhesion/cohesion model:

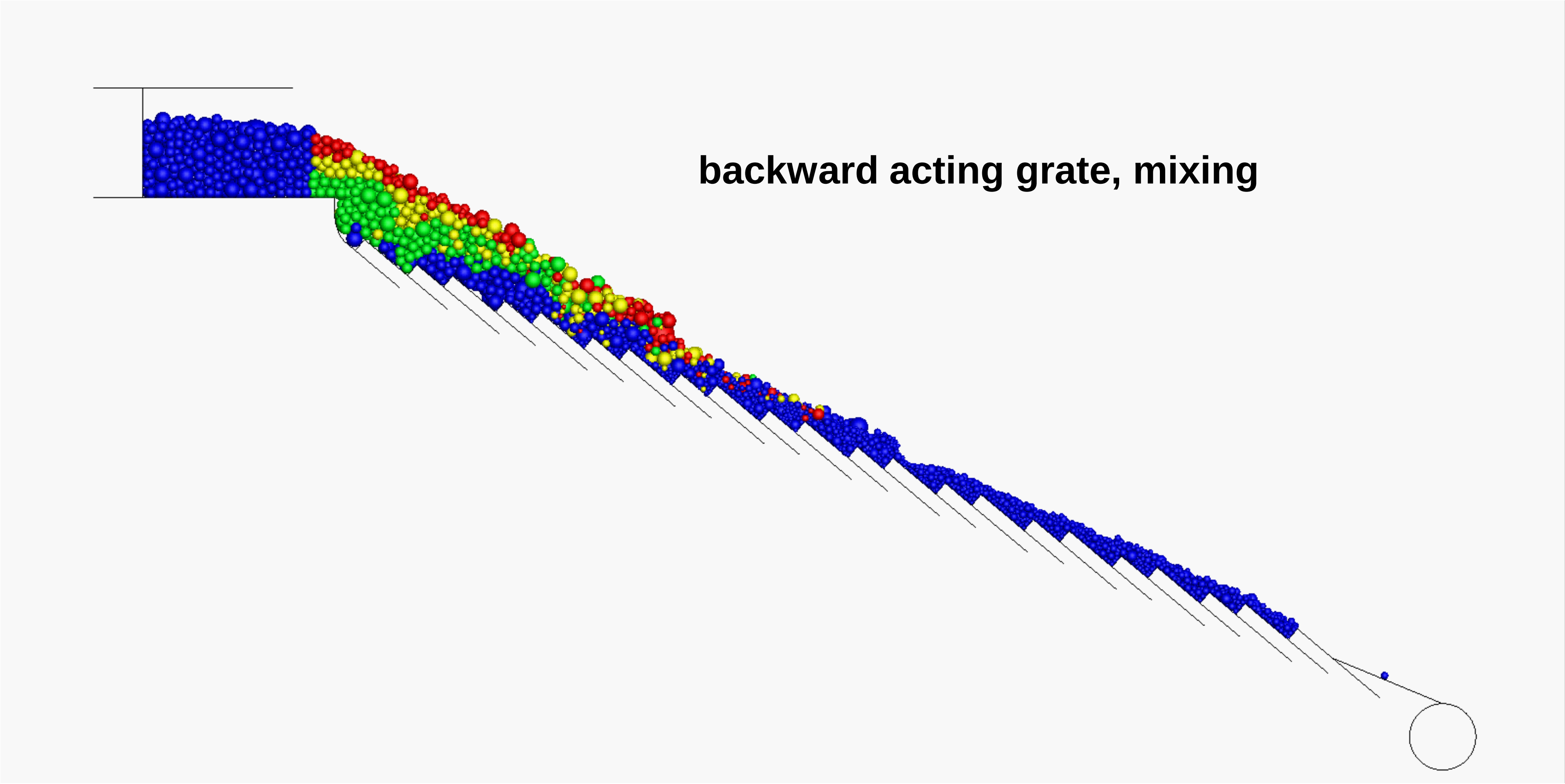
-> use advanced force description

residence times and mixing on different grates

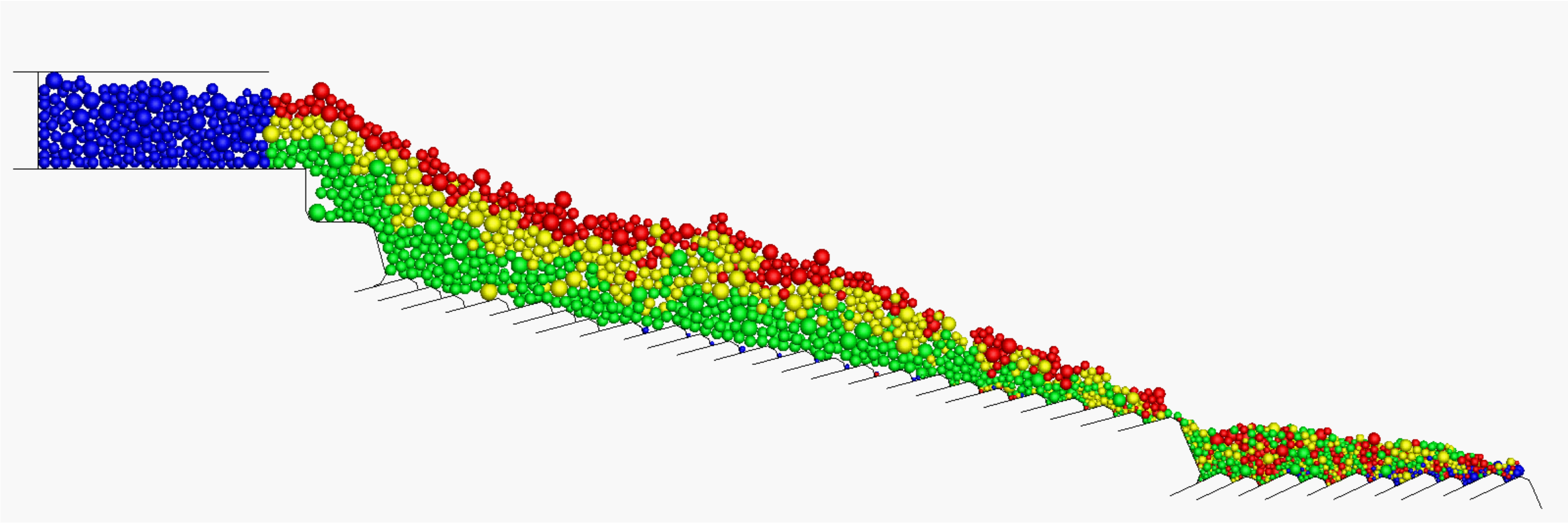
backward acting grate, particle age



residence times and mixing on different grates



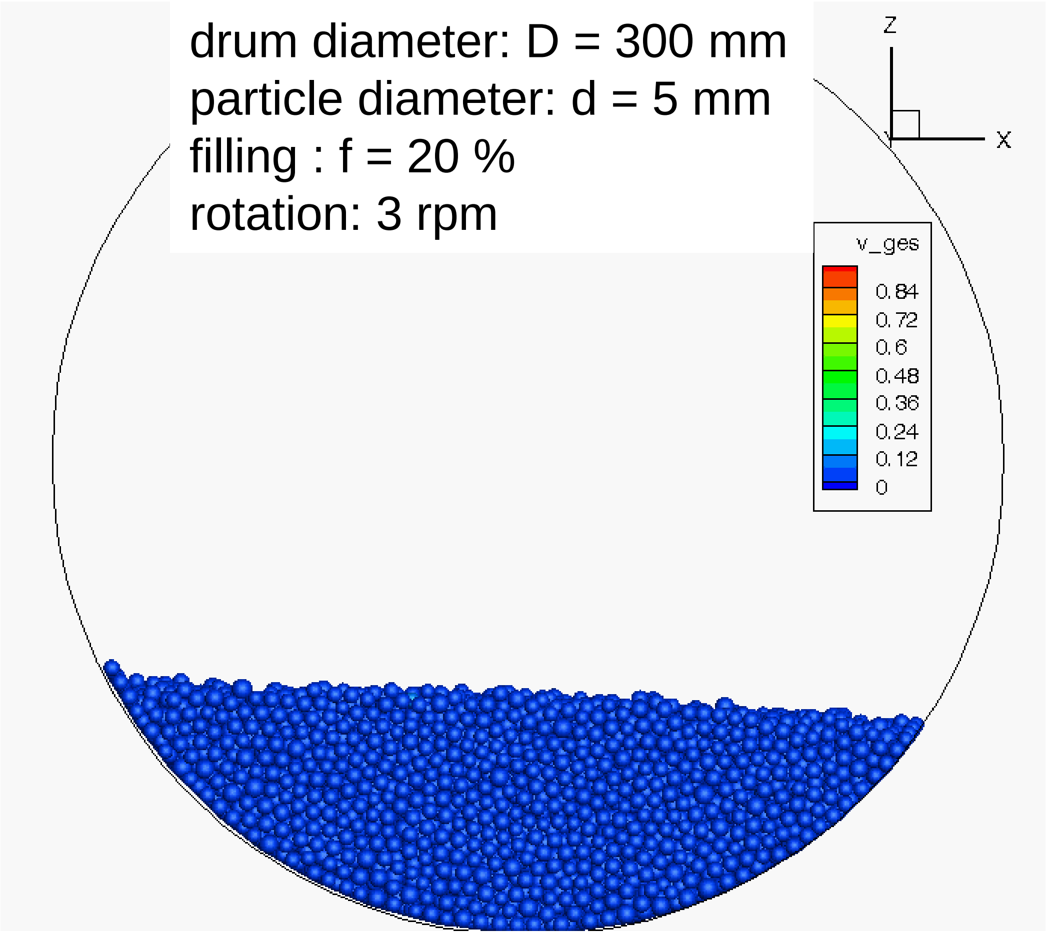
forward acting grate, mixing

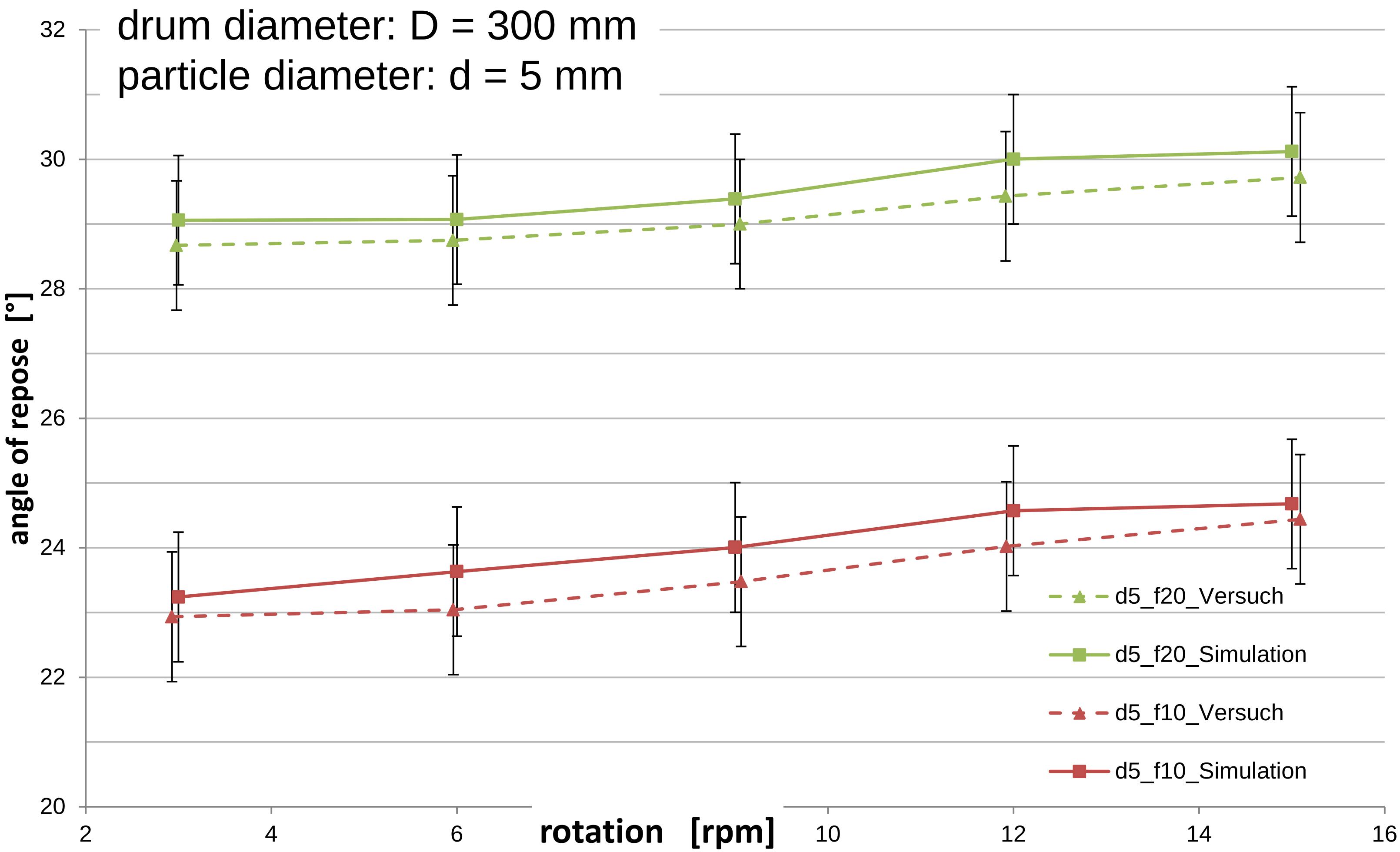


this is a rather static situation

dynamic angles of repose ???

drum diameter: D = 300 mm
particle diameter: d = 5 mm
filling : f = 20 %
rotation: 3 rpm

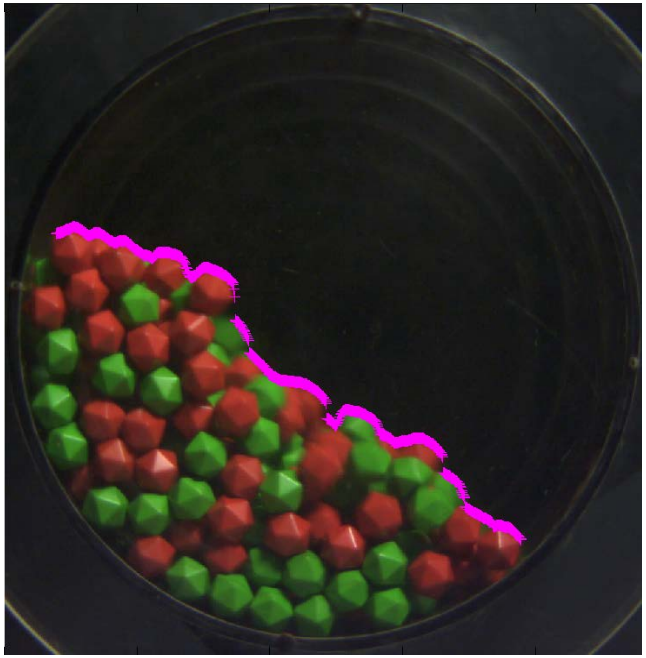


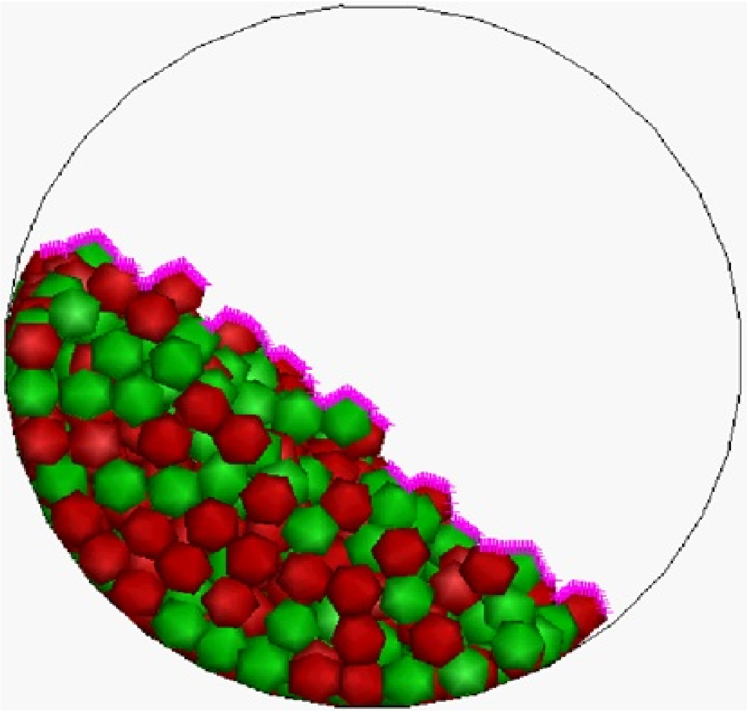

drum diameter: D = 300 mm
particle diameter: d = 5 mm
angle of repose [°]
rotation [rpm]
20
22
24
26
28
30
32
2
4
6
10
12
14
16
d5_f20_Versuch
d5_f20_Simulation
d5_f10_Versuch
d5_f10_Simulation

Is a more realistic particle geometry feasible ???

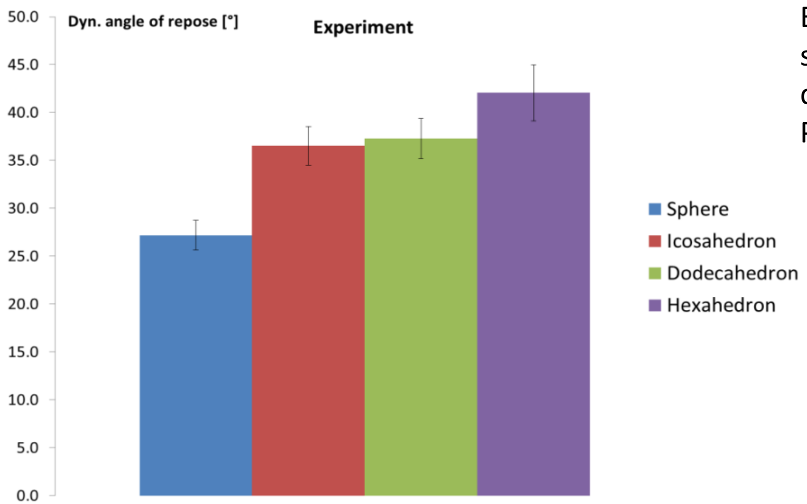
- clusters of spheres
- ellipsoidal objects, superquadrics,

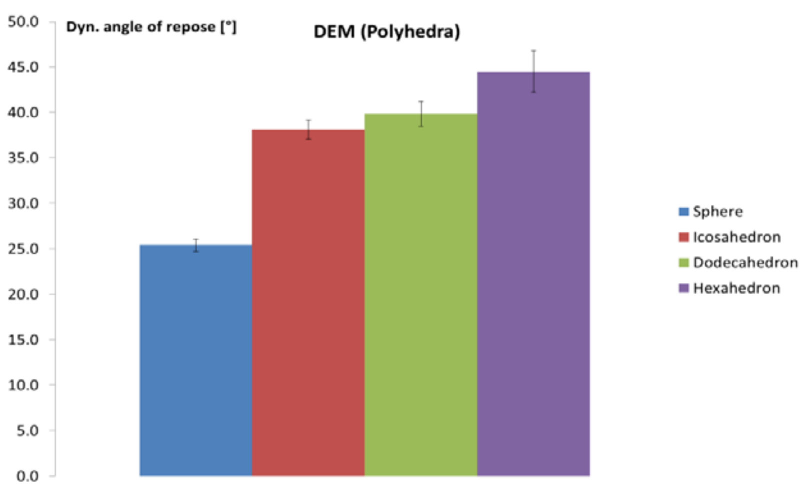
-> (smoothed) polyhedral definition

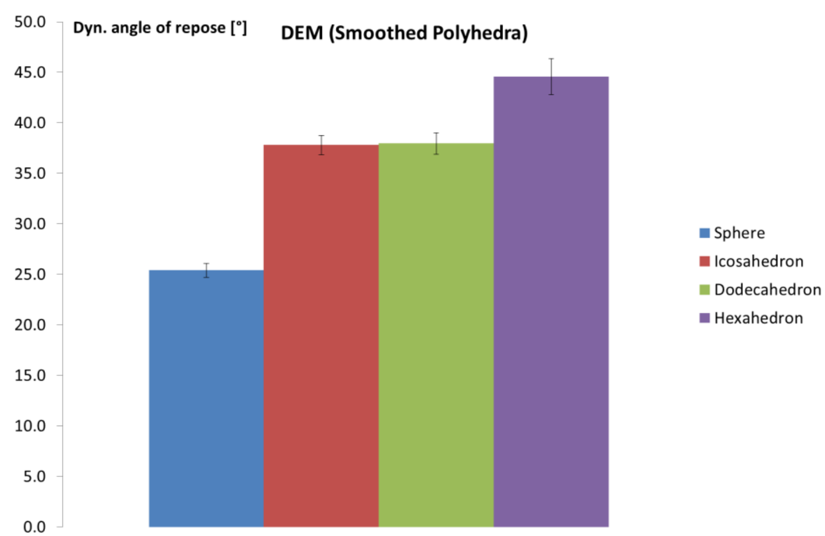




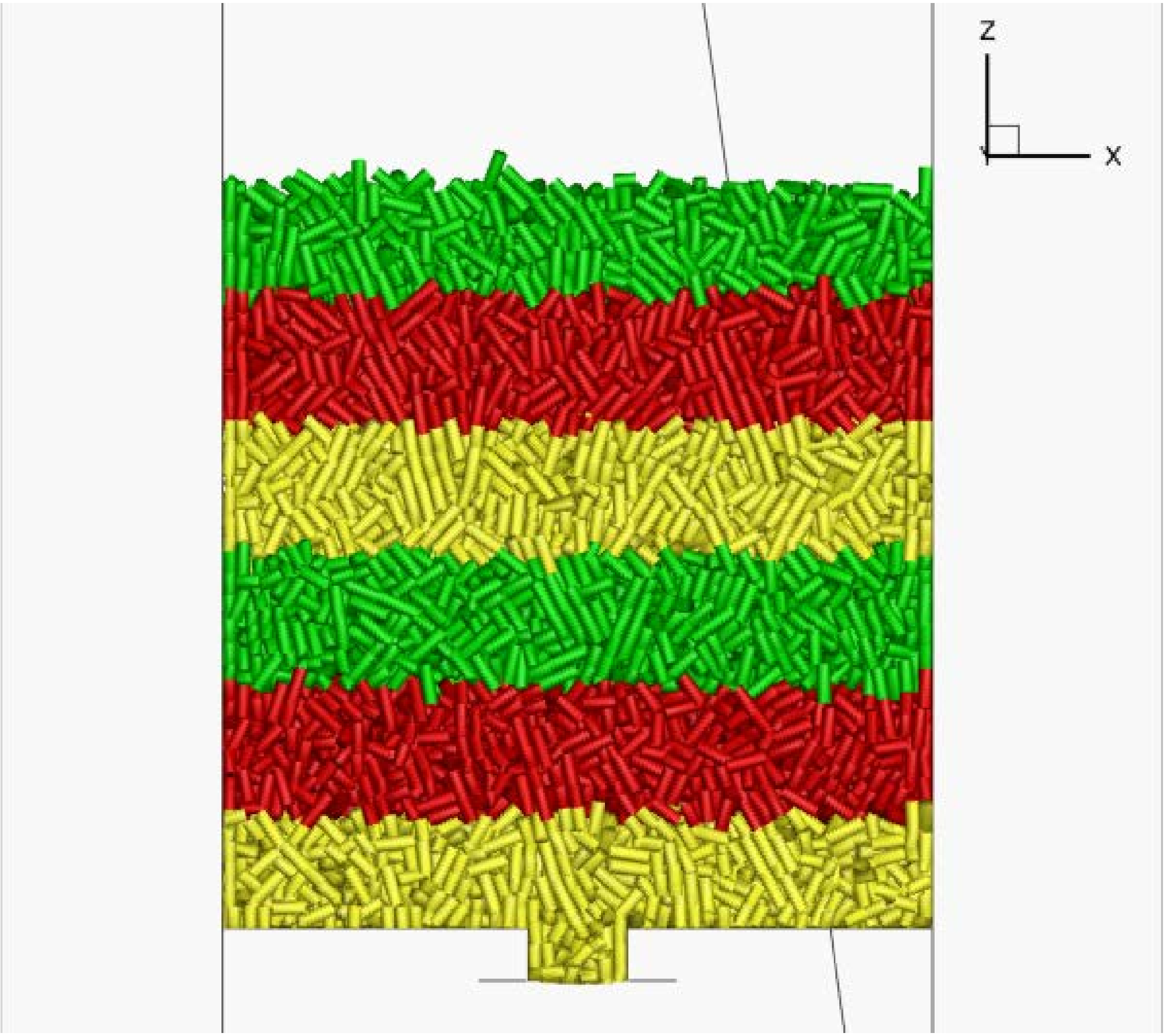
D. Höhner, S. Wirtz, V. Scherer:
Experimental and numerical investigation on the influence of particle shape and shape approximation on hopper discharge using the discrete element method
Powder Technology 235 (2013) 614–627



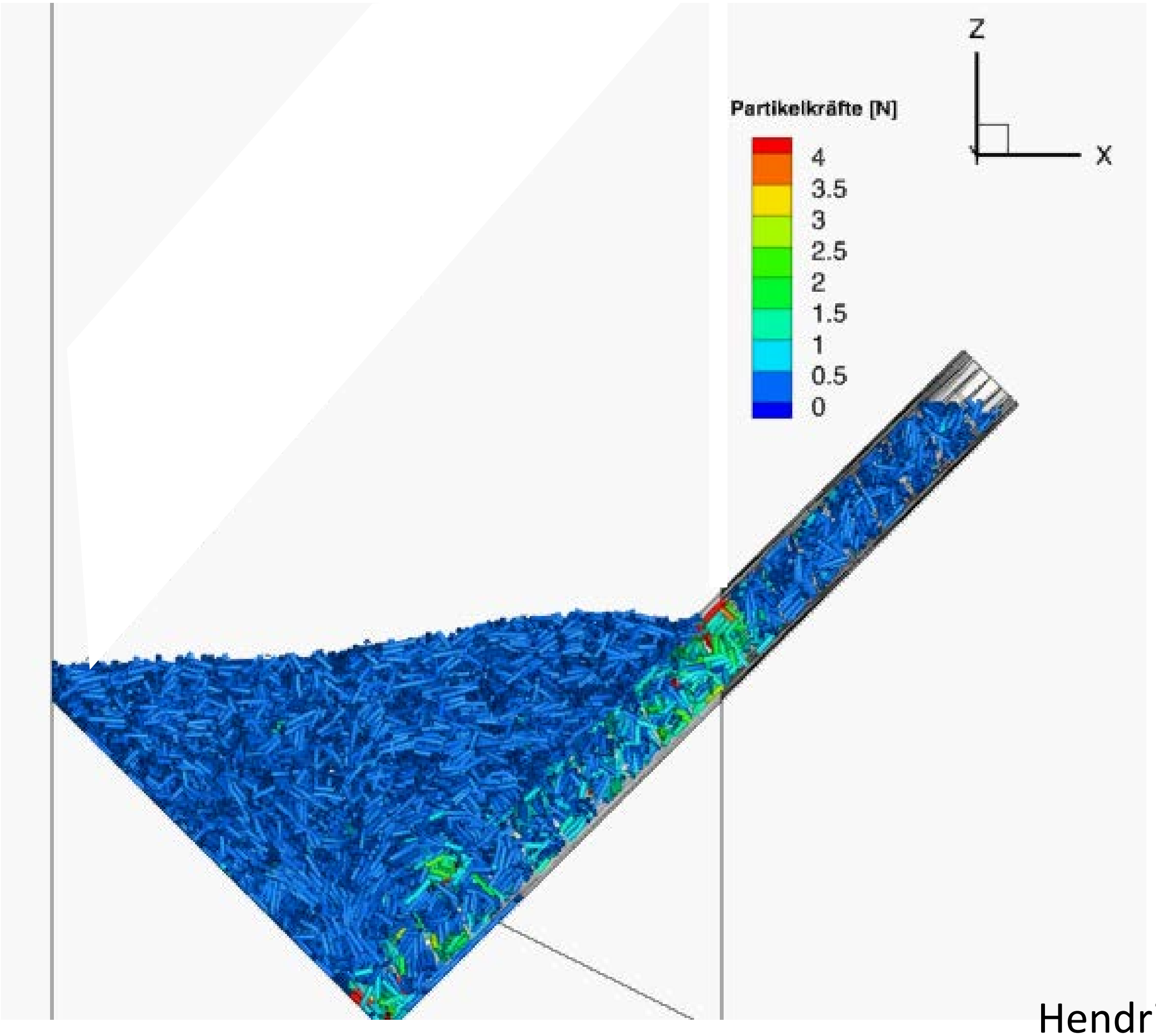




Silo Outflow of Wood Pellets

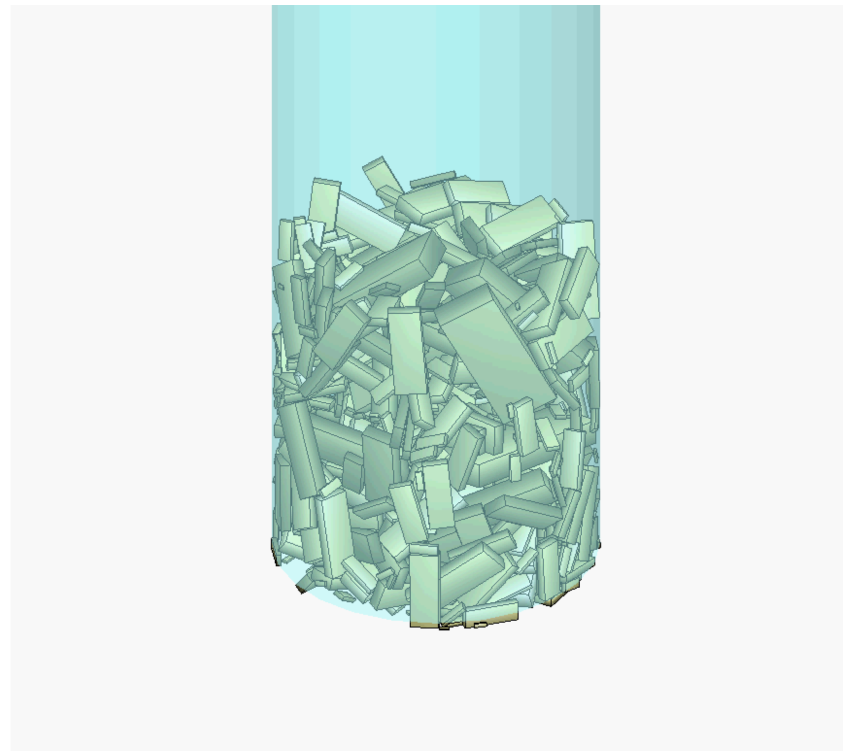


Forces in pellet transport with a screw feeder



Hendrik Komossa

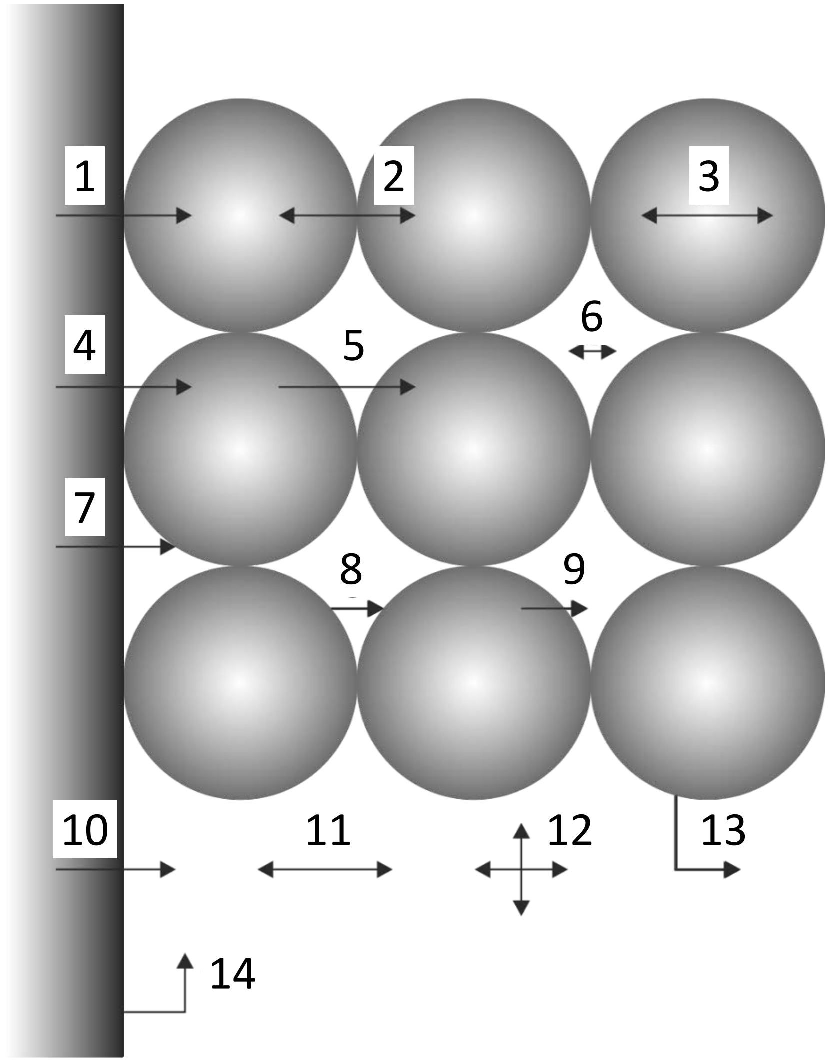
=> dumping wood-chips from a tube:



Florian Sudbrock

Heat transfer
and
transient heating

Heat transfer processes:



Conduction:

1. wall – particle
2. particle – particle
3. within the particles
4. wall – gas – particle
5. partikel – gas – particle
6. gas

Radiation:

7. wall – particle
8. partikel – partikel
9. partikel – gas
10. wall – gas
11. gas

Convection:

12. convection and mixing in gas
13. particle – gas
14. wall – gas

Inter-particle heat transfer:

Total heat flux:

$$Q_{P_1 \to P_2} = \left(\frac{1}{R_G} + \frac{1}{R_C} \right) * \Delta T$$

Conduction solid-solid (Hertz):

$$R_C = \frac{1}{2 * k_S * r_C}$$

k_S : conductivity particle

$$r_C = \left(\frac{3 * (1 - \gamma^2) F_N * r_{hm}}{2 * E_{hm}} \right)^{\frac{1}{3}}$$

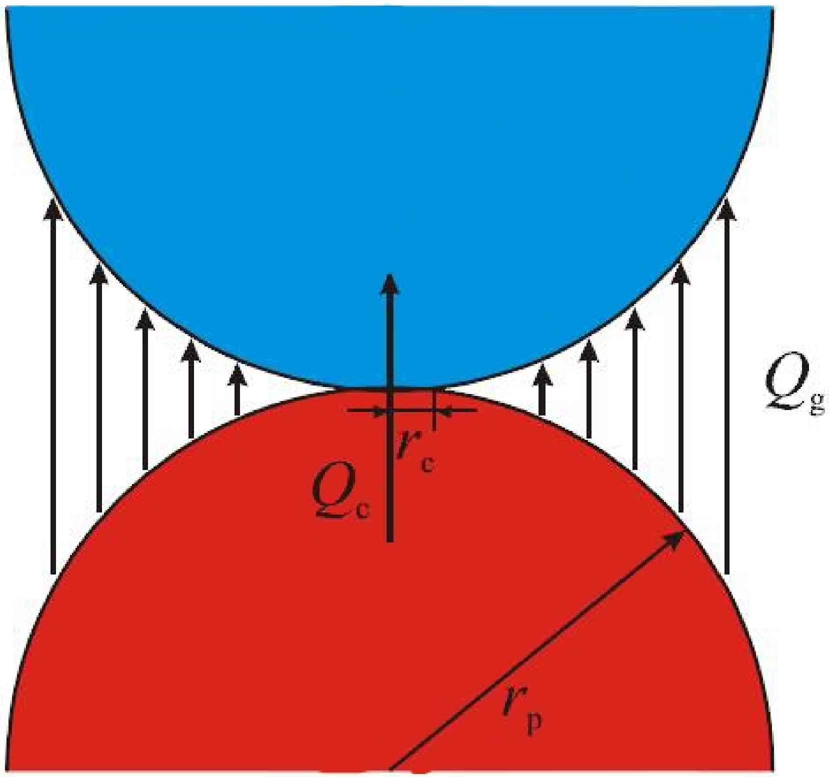
Conduction particle-fluid-particle

$$R_G = \frac{l_G}{A_G * k_G}$$

k_G : conductivity gas

$$A_G = 2 * \pi * {r_P}^2 - \pi * {r_C}^2$$

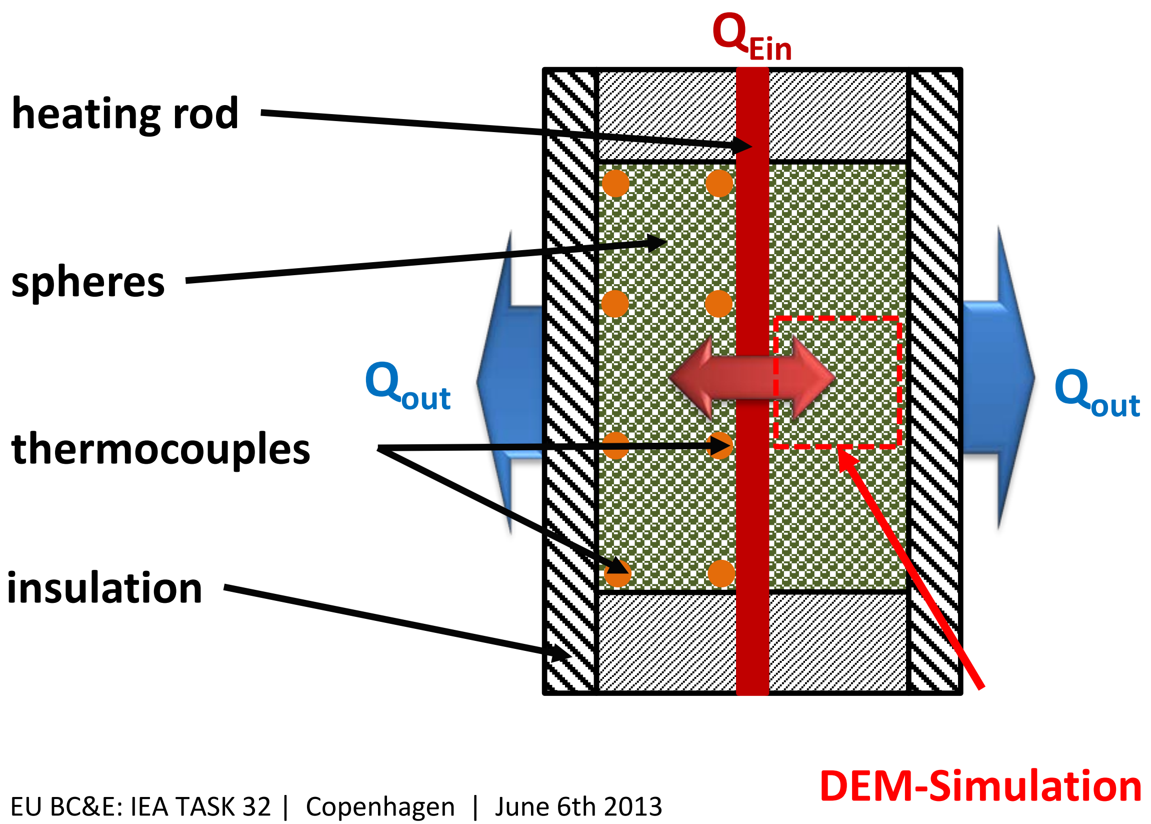
$$l_G = \frac{{r_P}^2 * \left(1 - \frac{\pi}{4}\right)}{r_P - r_C}$$

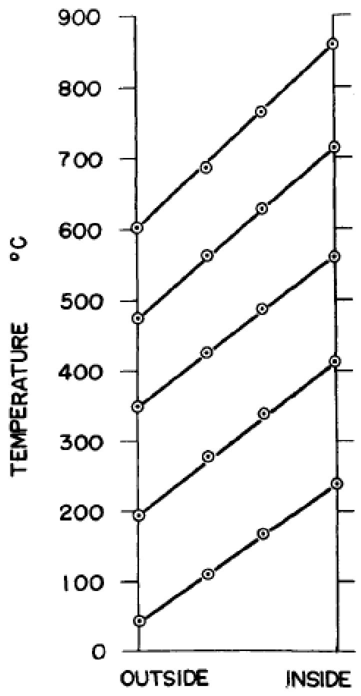


+ Radiation

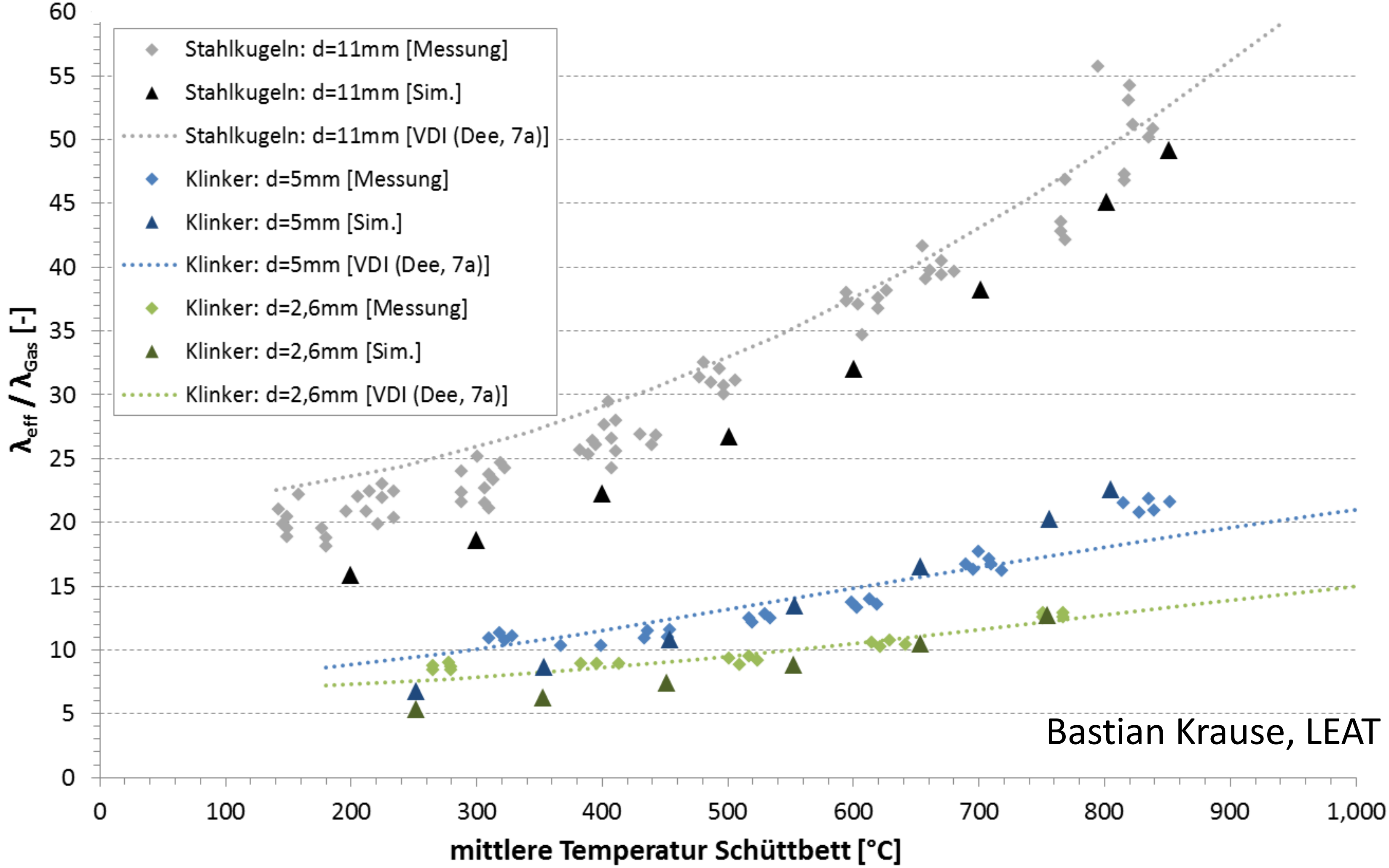
Verification of the combined conduction/radiation model

- Comparison with measurements Yagi & Kunii (1957)
- Steady state situation: $Q_{Ein} = Q_{aus}$
- computing and comparing the effective heat transfer coefficient

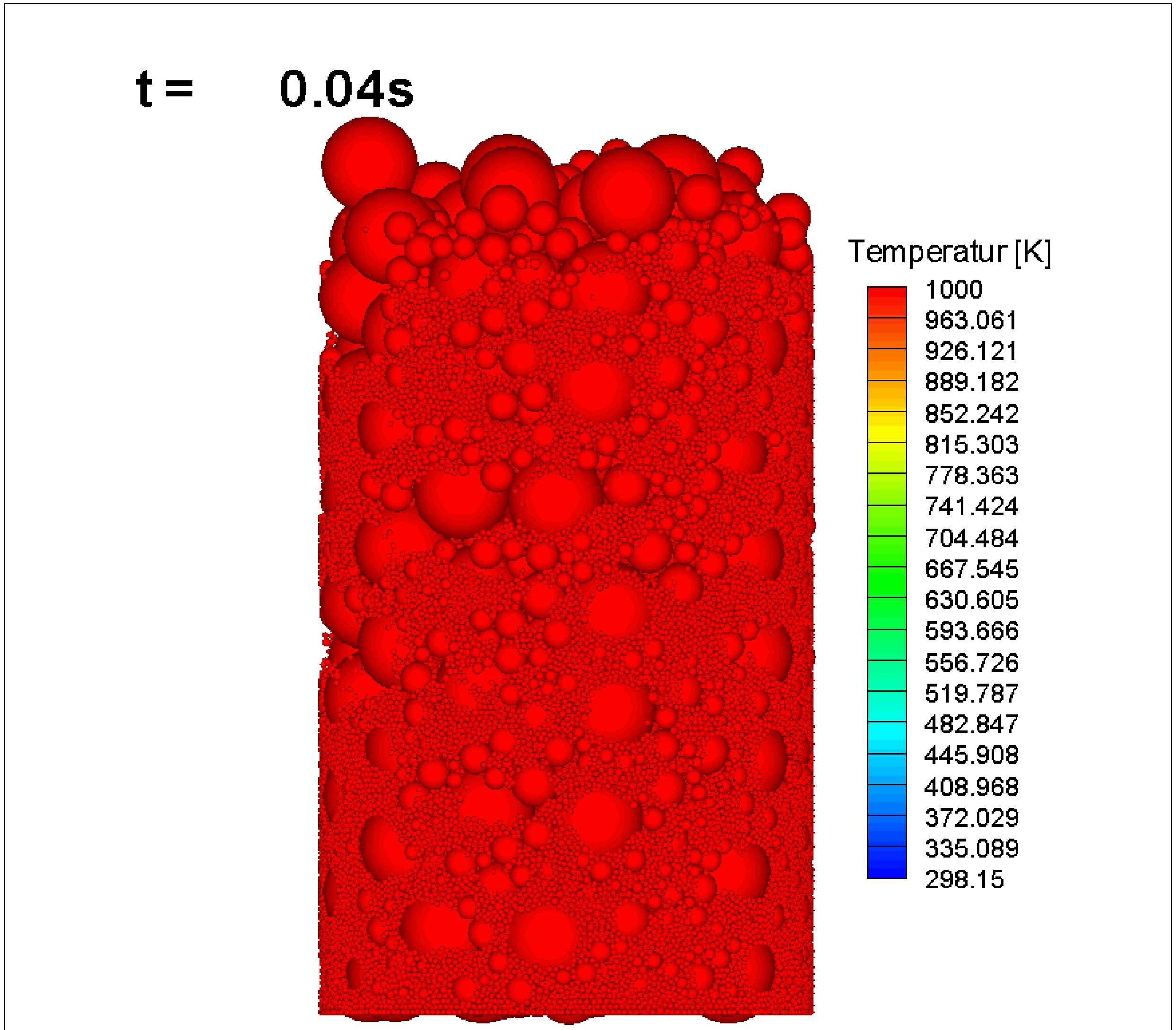




Effective heat conduction, comparison to measurements

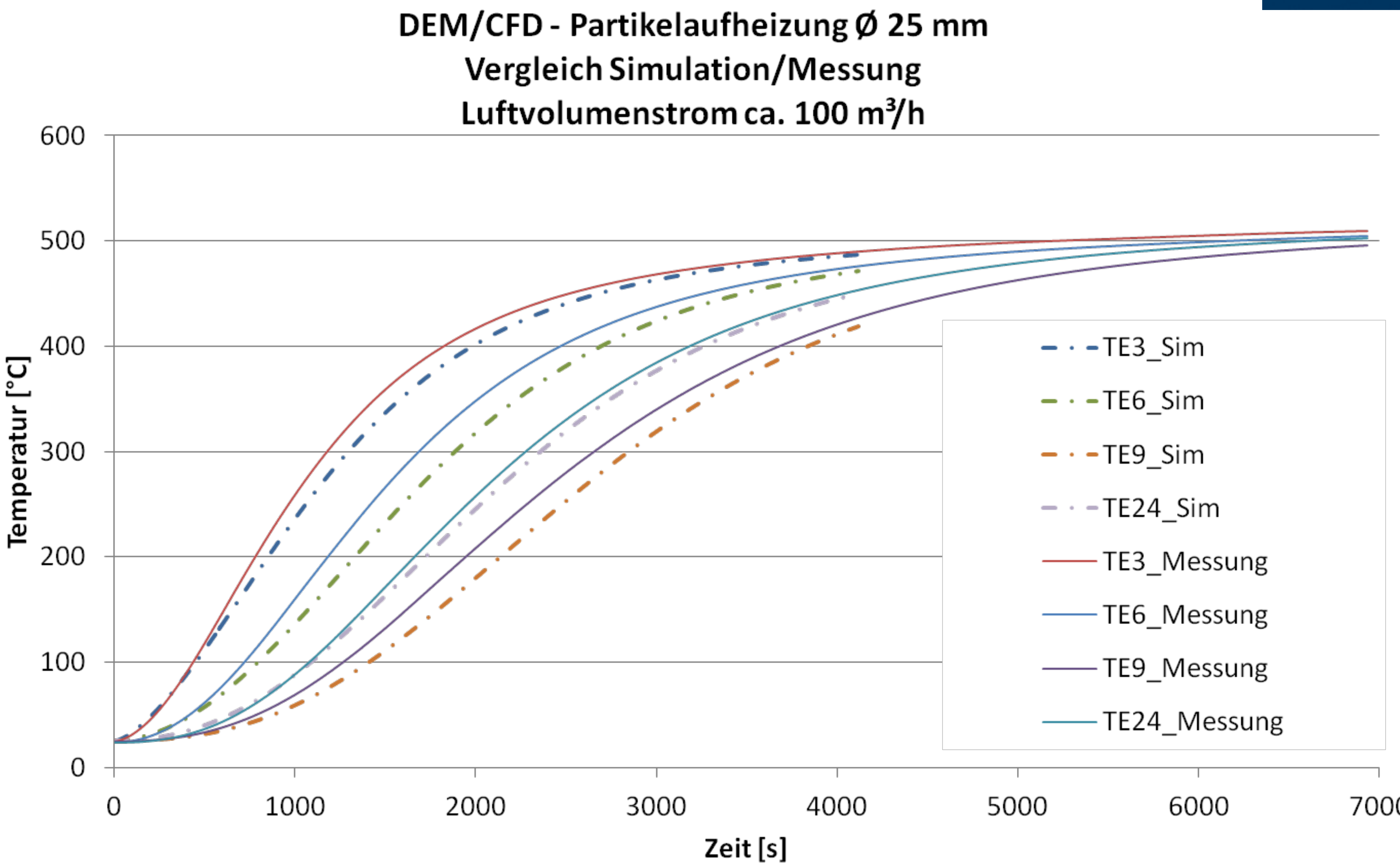


Convective cooling of cement clinker:



Jens Wiese, LEAT

Bei Durchströmung der Schüttung:



… well, then finally:

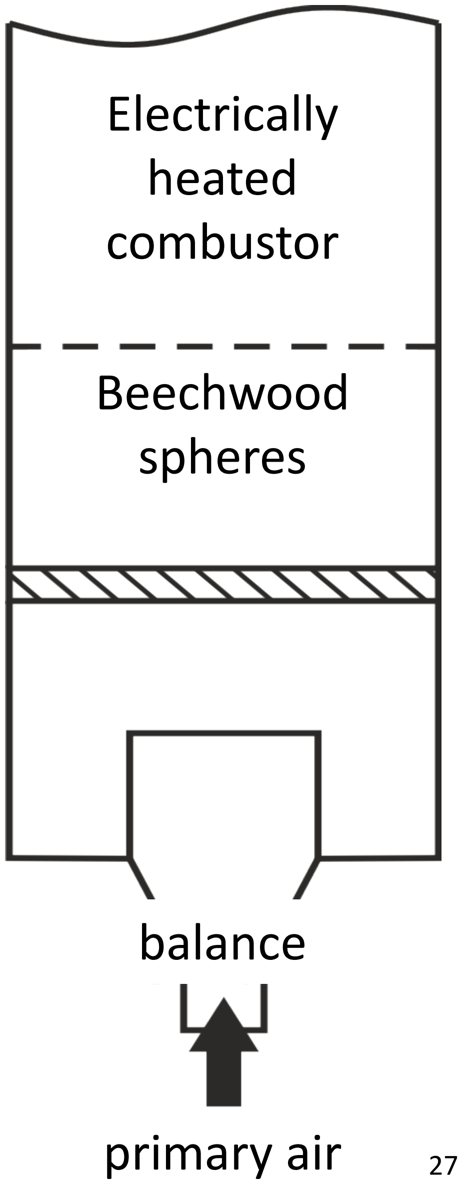
combustion

Doctorate Thesis, Björn Brosch, LEAT 2012

Combustion of wood spheres

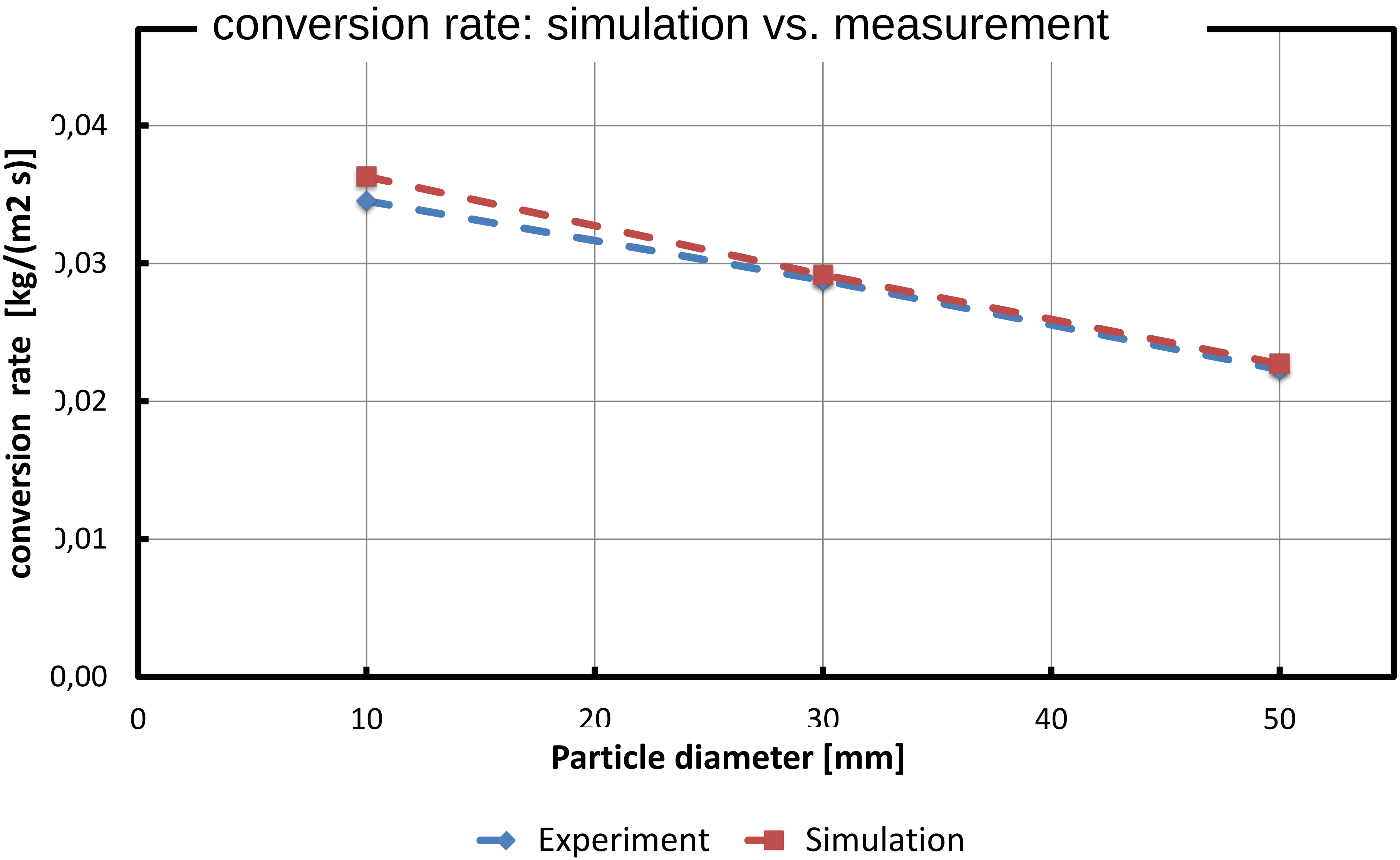
Measurements by Forschungszentrum Karlsruhe in KLEAA device[1)]

- ignition by radiation from the top
- primary air introduction from below
- constant downward reaction front velocity
- Mass loss of beech spheres with diameters of 10 mm, 30 mm and 50 mm
- consideration of heat loss



[1)] Bleckwehl, S.: Doctorate Thesis, KIT / Univ.Stuttgart, 2010

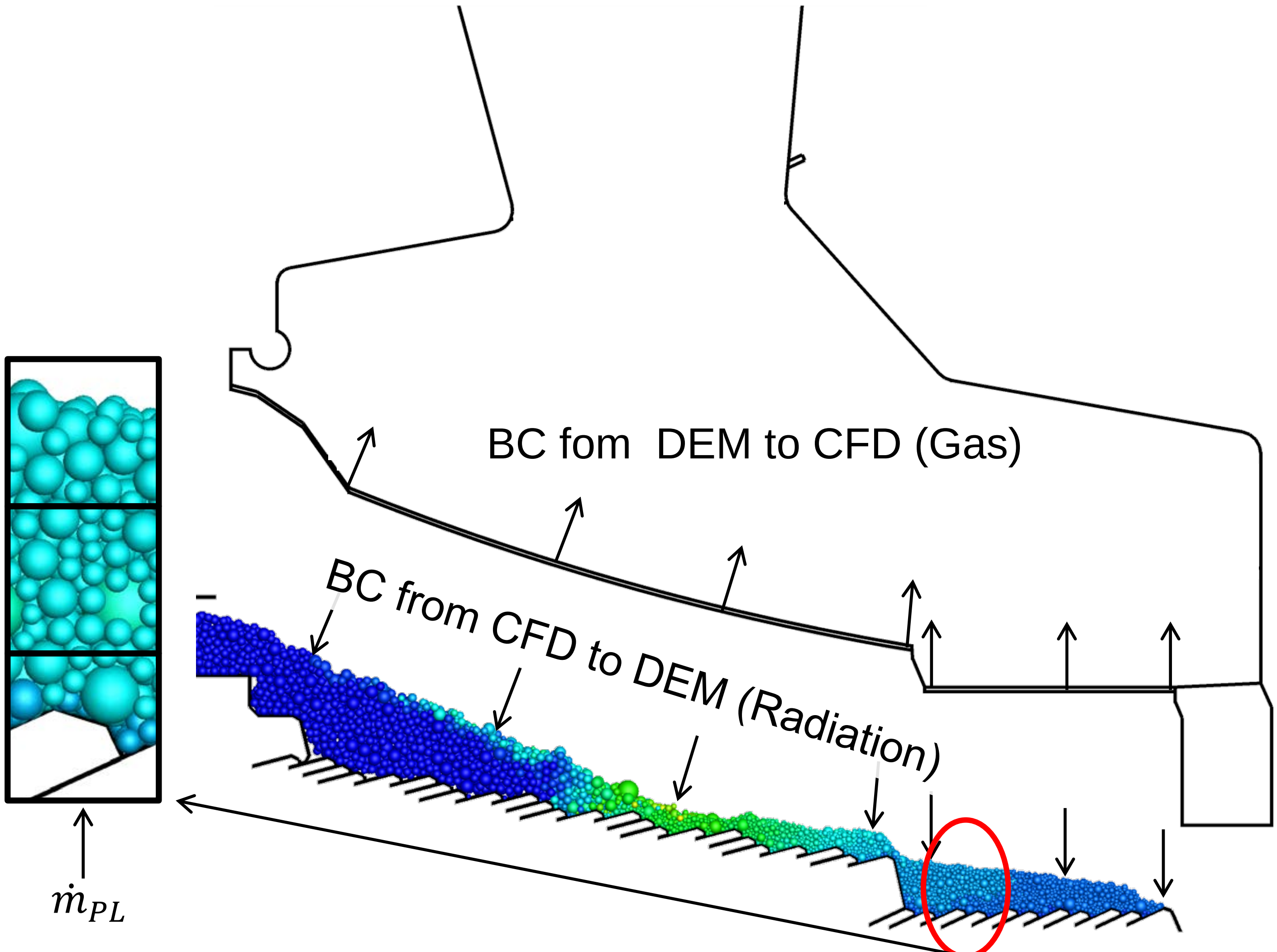
Abbrand einer ruhenden Schüttung



Coupling to a CFD code

CFD-model

DEM-model



Basic data, MSW incinerator, 57 MW_{th}

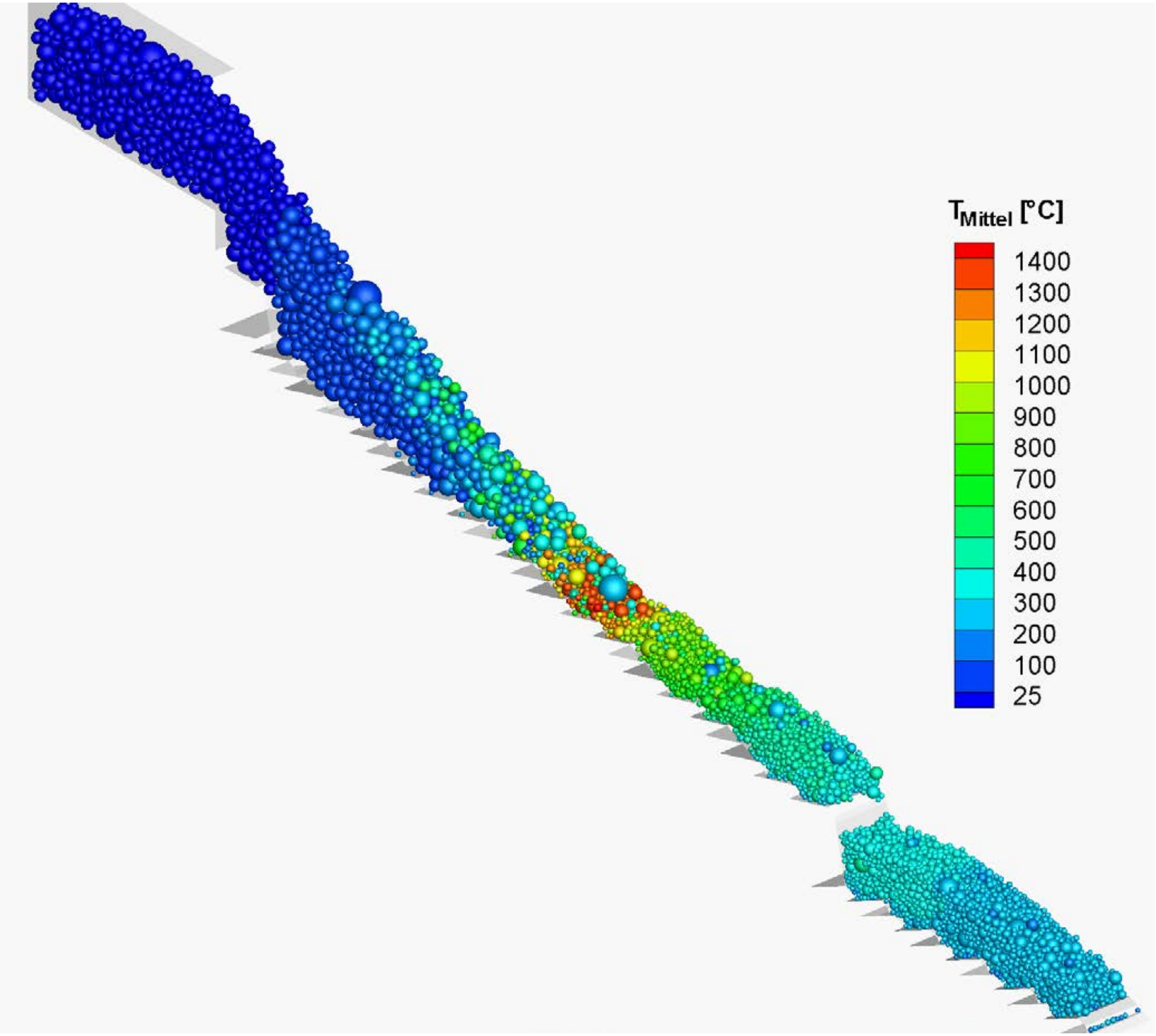
CFD-Model (Fluent, 3-dimensional, steady state solution(s))

- Turbulence: k-ω SST
- Reaktion: Eddy Dissipation & Finite Rate Chemistry
- Radiation: P1

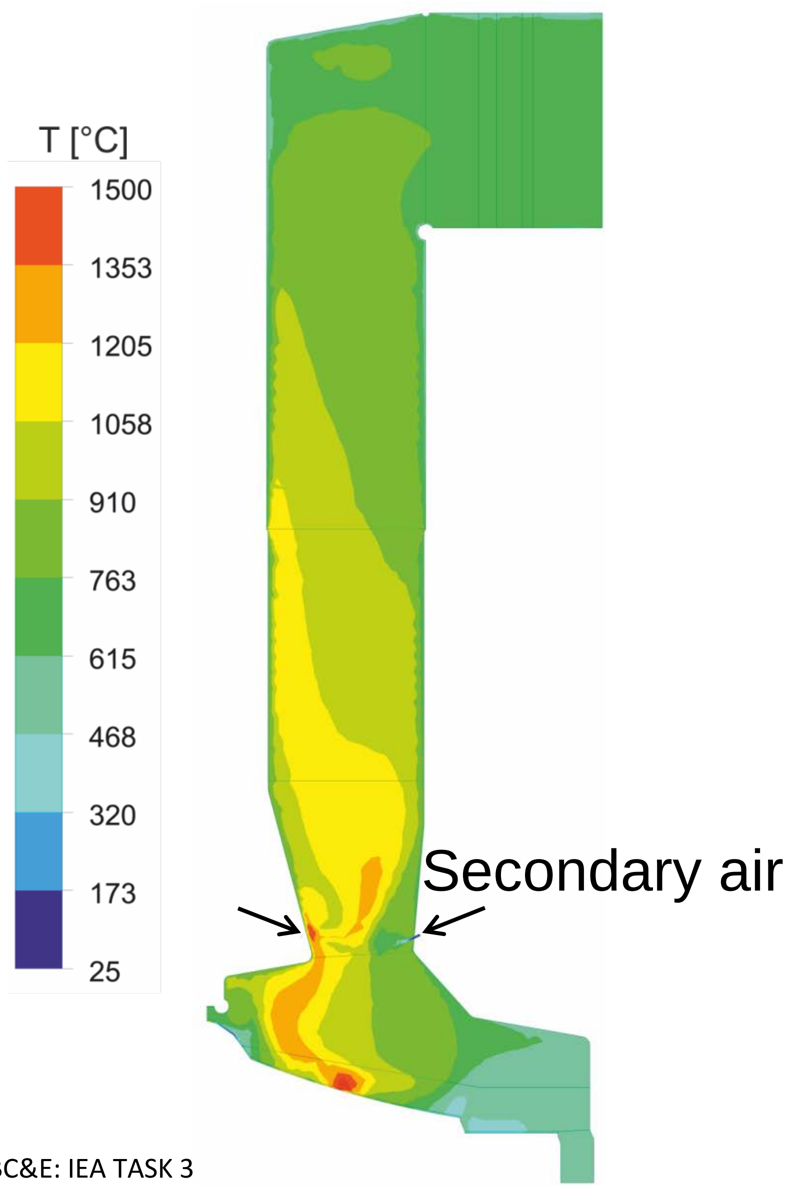
DEM-Model (3-dimensional, strip in the grate center, unsteady)

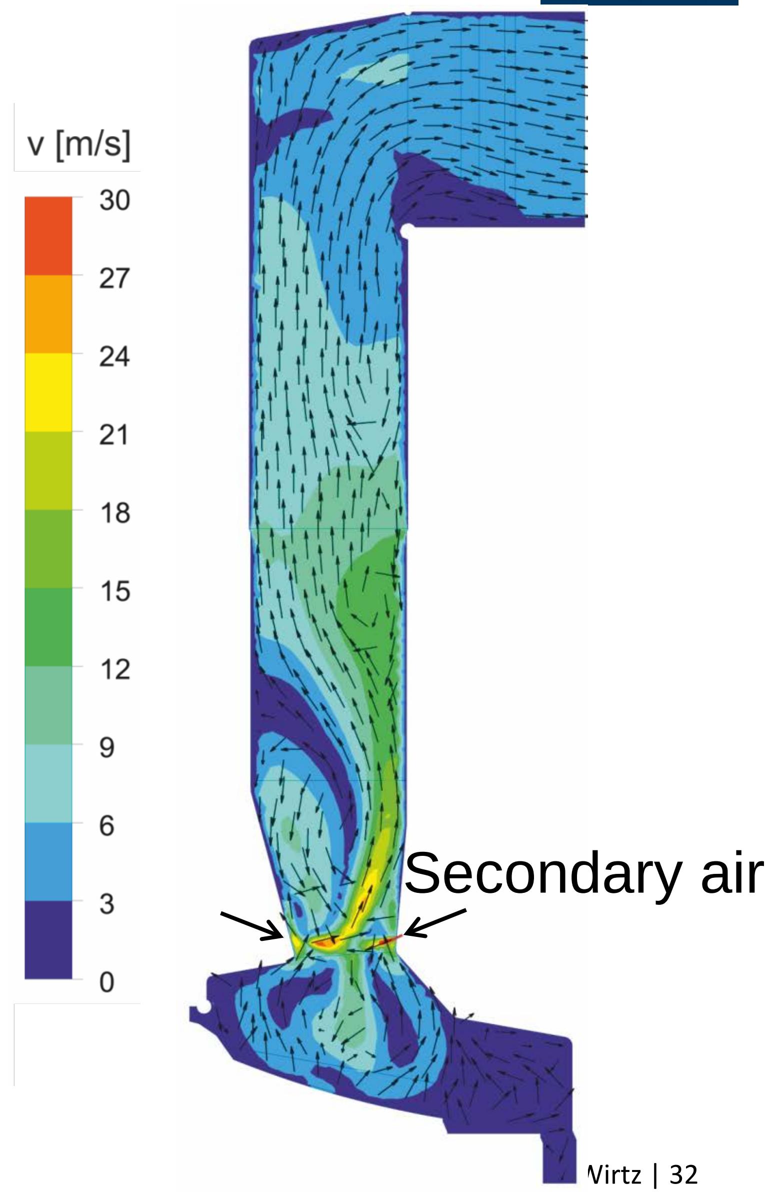
- Number of particles: ~8000
- LHV: 10 MJ/kg
- Mass fraction wood: 15 %
- Mass fraction plastics: 15 %
- Mass fraction organic: 30 %
- Mass fraction inert: 20 %
- Mass fraction balance: 20 %

Conversion on the MSW grate

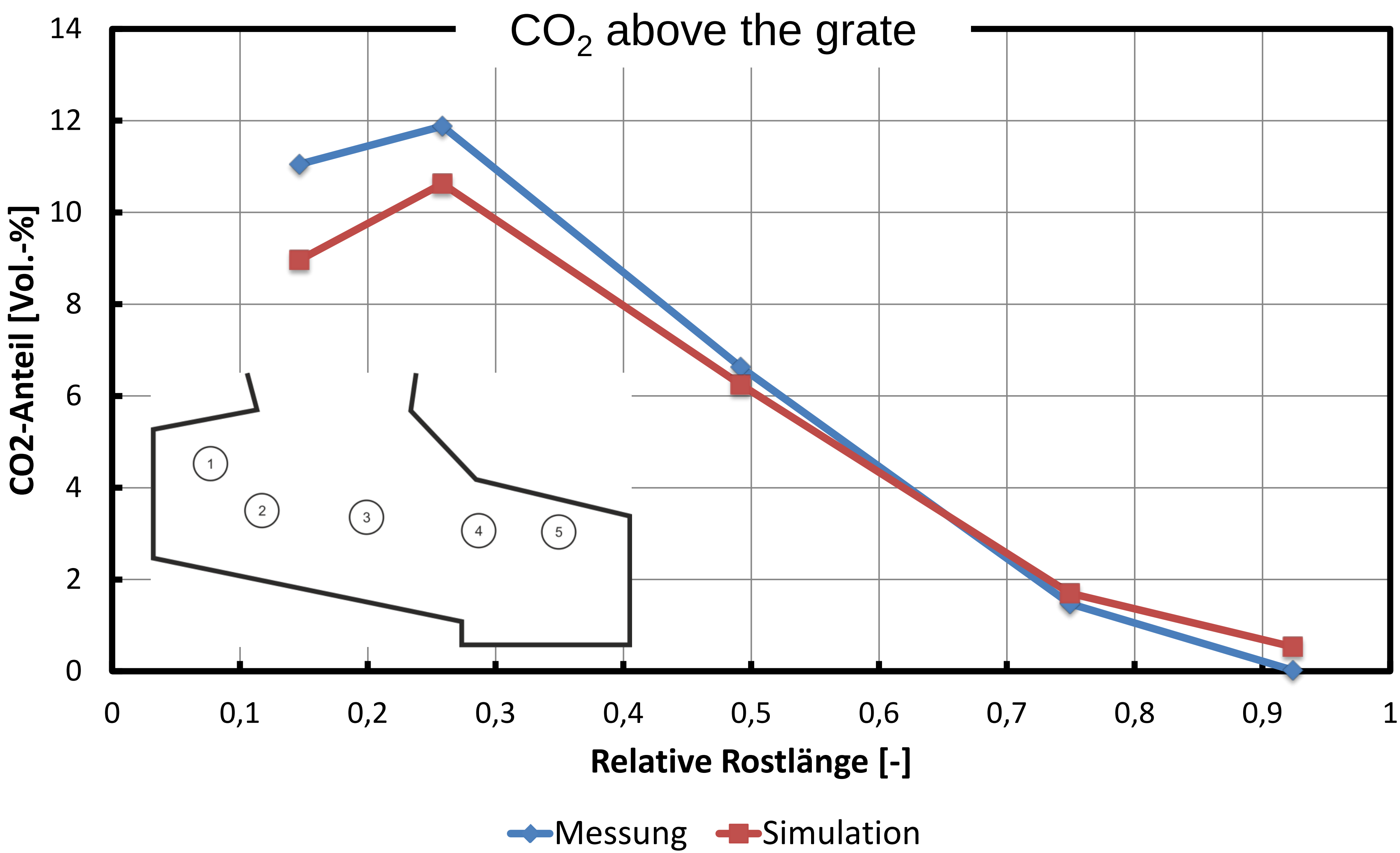


Corresponding 3D simulation of the MSW furnace

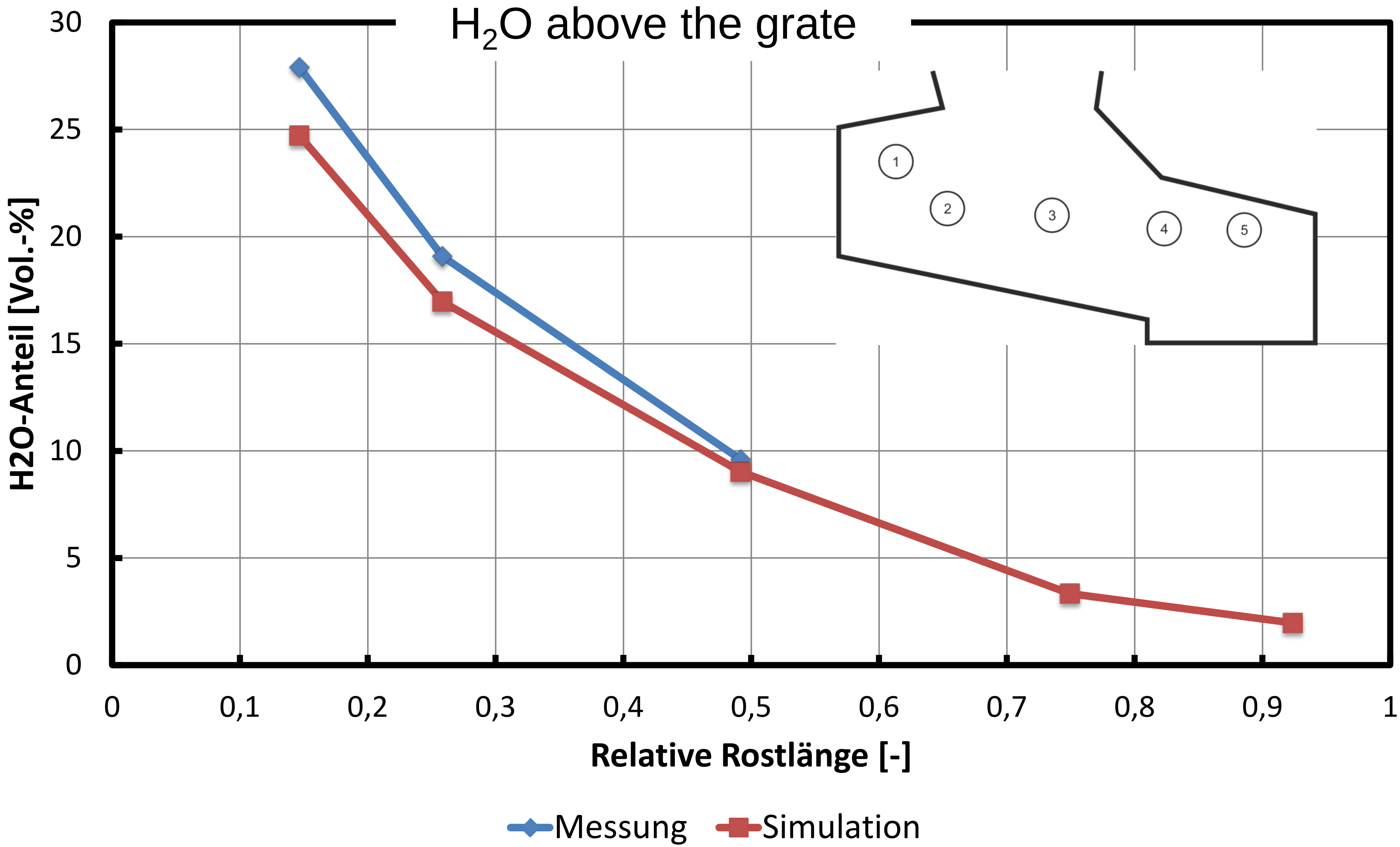




Simulation eines Vorschubrosts



Simulation eines Vorschubrosts



Summary:

- Grate firing systems are strongly influenced by the interaction between the grate and the furnace atop.
- Correct representation of heat transfer mechanisms is required.
- DEM simulations allow the description of more and more mechanical details.
- DEM coupling with furnace codes is feasible.

The DEM-Team @ RUB-LEAT:

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- Jennifer Hold
- Dominik Höhner
- Bastian Krause
- Harald Kruggel-Emden
- Hendrik Komossa
- Tobias Oschmann
- Gerd Stein
- Florian Sudbrock
- Kevin Vollmari
- Jens Wiese
- Frank Wissing

The financial support of
DFG, AiF, Energie.NRW,
Doosan Lentjes , …
is acknowledged

Thank you
for your attention!