Positron Emission Particle Tracking – A Comprehensive Tool for Characterization of Fluidized Beds with Secondary Gas Injection

T. Hensler[a], M. Tupy[b], T. Strer[a], T. Pöschel[b] and K.-E. Wirth[a]

[a] Institute of Particle Technology, University Erlangen-Nuremberg, Germany
[b] Institute for Multiscale Simulation , University Erlangen-Nuremberg, Germany

Introduction

Fluidized beds with secondary gas injection

Characteristics of fluidized bed technology:

- intense mixing of solids
- excellent heat and mass transfer
- easy solids handling

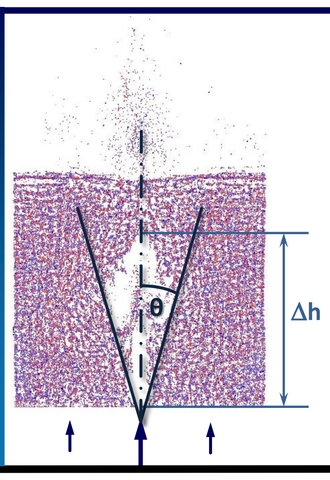
Secondary gas injection:

- heterogeneous catalysis
- fast reactions
- two zone reactors
- avoid undesired reactions

Efficient operation requires detailed knowledge on the **dimensions of the reaction zone** and the **residence time behavior** of the solid particles

Requirements

Conventional characterization methods



Determination of the characteristics of the system:

- 1-ε: solids concentration
- Δh: penetration depth of the jet into the suspension phase
- θ: half jet opening angle

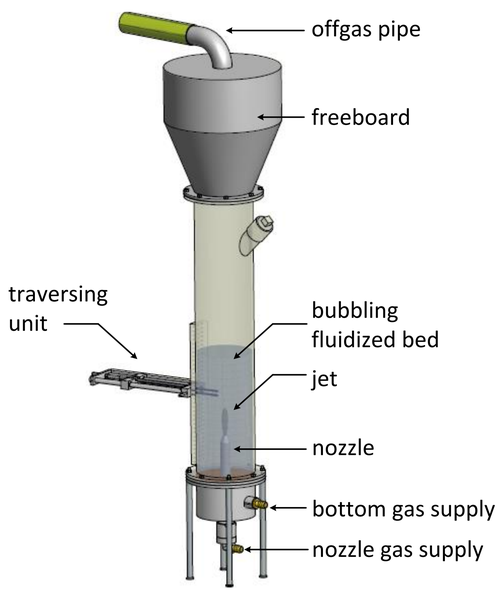
Measurement techniques:

- invasive
  - capacitance probes
  - optical fiber probes
- non-invasive
  - X-ray CT

behavior of single particles cannot be detected!

Experimental

Material and setup



Plant characteristics:

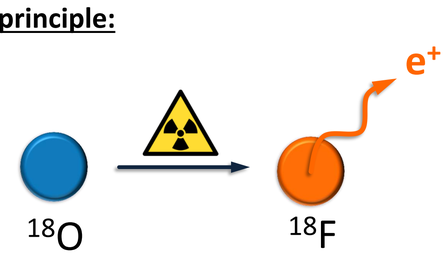
- hollow steel cylinder:
  - inner diameter: $d_{cylinder}$ = 190 mm
  - length: $l_{cylinder}$ = 1900 mm
- gas distributor:
  - porous sintered metal base plate
  - cylindrical nozzle with conical top section; $d_{orifice}$ = 10 mm
- bed inventory:
  - fixed bed height: h_0 = 500 mm

Material properties:

- process fluid: pressurized air
- solids:
  - glass beads; $x_{1,2}$ = 732 µm
  - ρ_p = 2480 kg m^{-3}

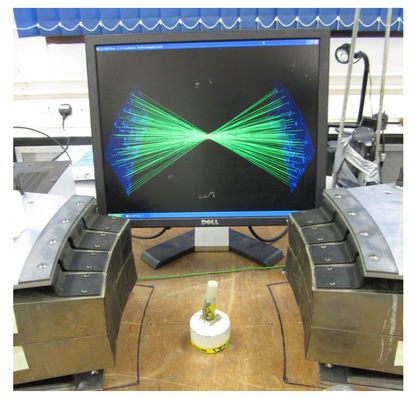
Positron emission particle tracking (PEPT)

Basic principle:



- β$^+$-decay
- annihilation of e$^+$ and e$^-$
- emission of back-to-back γ-rays
- tracer activity: 20-40 MBq

20 – 40 mio. decays per second

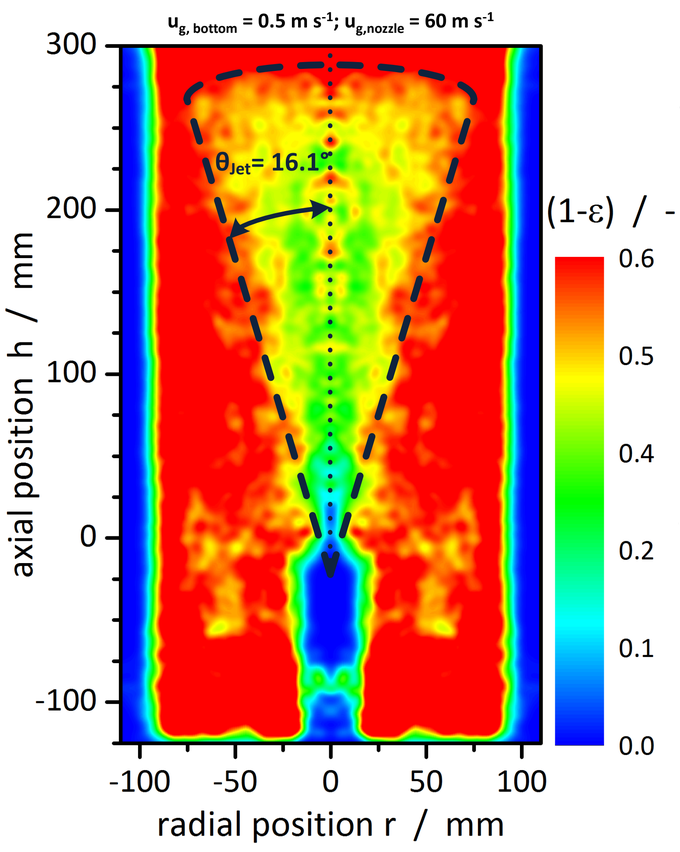


Detection of radiation:

- ADAC Forte γ-ray cameras
- sampling frequency: 100 kHz

Results

Solids concentration profile and residence time behavior of a single particle



solids holdup (1-ε)

Methodology:

- derivation of continuous fields from discrete particle positions [1]

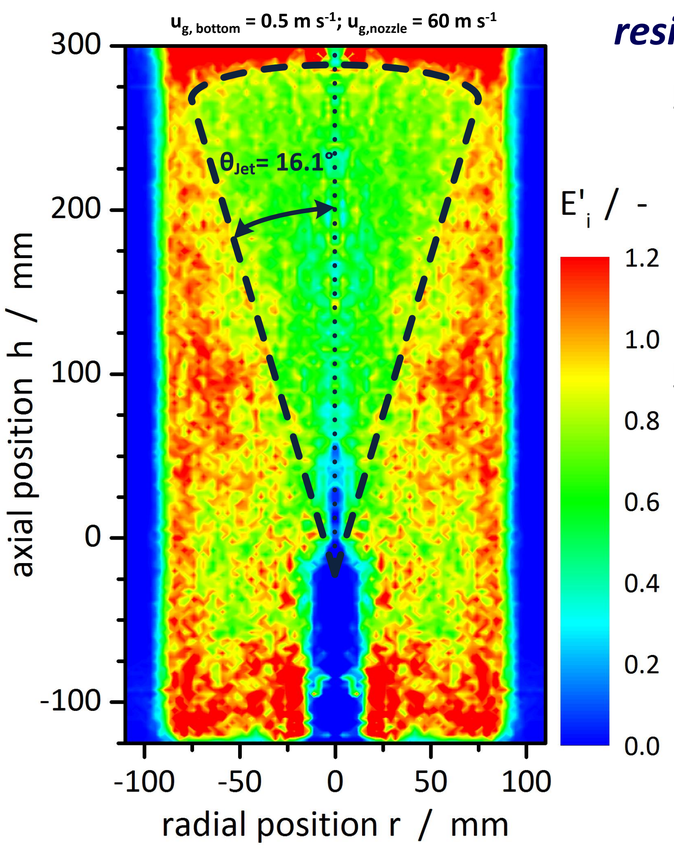
$$\rho_m(x,t) = \sum_i m_i \phi(x - x_i)$$

$$(1-\varepsilon) = \frac{\bar{\rho}_m(x)}{\rho_s}$$

[1] I. Goldhirsch, Stress, stress asymmetry and couple stress: From discrete particles to continuous fields, Granular Matter, 12 (2010) 239-252

Results:

- suspension phase: solids holdup close to minimum fluidization condition
- jet region distinguished by reduced solids holdup
- dimensions of the jet region:
  - **half opening angle: θ_{jet} = 16.1°**
  - **penetration depth: Δh_{jet} = 275 mm**



residence time density E'$_i$

Methodology:

- relative residence time density E'$_i$

$$E_i' = \frac{\sum_k \Delta t_{i,k}}{t_{tot}} \cdot \frac{V_{tot}}{\Delta V_i}$$

Results:

- suspension phase: **E'$_{sus}$ ≈ 1.0** characteristic for ideally mixed systems
- jet region: **E'jet = 0.699**

„The residence time of a single particle in the jet region is 69.9 % of that in an equally sized volume element in the suspension phase.“

Conclusions

Summary and outlook

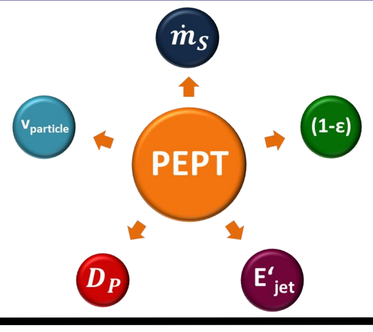
PEPT…

… is a **non-invasive** tool for analysis of the behavior of single particles

… provides results with high temporal & spatial resolution

… provides **data that cannot be obtained by conventional measurement techniques**

… delivers important parameters for design and operation of reactors in continuous or batch mode



Positron emission particle tracking:

Powerful tool for design and optimization of fluidized bed reactors with a well defined reaction zone

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website: http://www.lfg.uni-erlangen.de