Experimental investigation of single-particle gasification

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Experimental investigation of single-particle gasification

Outline

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2. The HITECOM Reactor
3. Development of a single particle holder
   - Requirements / overview particle holder
   - Overview adhesive-fixation
   - Integration in HITECOM-System
4. Results and Discussion
   - Feedstock characterization
   - Investigation of single-particle reactions
   - Determination of kinetic parameters
   - Further results
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Experimental investigation of single-particle gasification

**Motivation**

- Spatial and time resolved characterization of thermochemical conversion of single particles in directed flow at $T < 1400 \, ^\circ\text{C}$ and up to 40 bar for fundamental research and advanced CFD validation
  - Temperature map on the particle surface
  - Temperature- and concentration profiles in the boundary layer around particles

**Challenges:**

- High pressure
- High temperature
- Reactive gases
- Integration of optical ports
- Single-particle gasification
2. The HITECOM Reactor
Overview

Specifications:
- Magnetic suspension balance
- Ceramic flow tube
- $T_{\text{MAX}}=1400 \, ^\circ\text{C}$, $p_{\text{MAX}}=40 \, \text{bar}$
- Four optical ports (perpendicular to the flow direction; material: sapphire)
- Feed gases: CO, CO$_2$, H$_2$O, H$_2$, O$_2$, N$_2$ and Ar (1 – 200 l/min)

Challenging Task:
- Integration of particle holder
3. Development of a single particle holder
Demands for single particle holder

- Fixation various particles (1.0 – 4.0 mm)
- Temperature resistance (up to 1400 °C)
- Rigidity (no natural oscillation)
- Tolerance of shrinking particles
- good fixation in direct flow
- Minimal flow field distortion
- Compatibility with magnetic suspension balance / reactor

Development of new concepts for the fixation of single-particles in direct flow
  - Combination with magnetic suspension balance
  - Modification of the HITECOM-System
Single particle holder

Overview

Traditional particle holder with wire basket

Disadvantages:
- Disruption of the flow field
- Sensitive against direct flow (vibration)
- Problematic measurement of the boundary layer
- Not suitable for single particles

Classical:

<table>
<thead>
<tr>
<th>Wire-fixation</th>
<th>Ceramic-fixation</th>
<th>Adhesive-fixation</th>
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</table>

Alternatives:

Task: Realization of a vibration-free particle holder tolerant against particle-shrinkage
Particle holder type C – **Adhesive-fixation**

**Advantages:**
- suitable for direct flow
- vibration-free
- excellent reusability / easy of assembly
- temperature resistant
- low error rate
Single particle holder

**Particle holder type C – Adhesive-fixation (C.1)**

Lignite I (T=900 °C, p=1.0 bar CO$_2$)
Single particle holder

Particle holder type C – Adhesive-fixation (C.2)

Lignite I (T=900 °C, p=1.0 bar CO₂)
4. Results and discussion
Results and discussion

Feedstock characterization

- Characterization of single-particles of three different feedstocks (lignite and hard coal)
- Characterization of a synthetic mixture of several single-particles of the three feedstocks (traditional methods)
  - Ultimate analysis (DIN 517 24/32)
  - Proximate analysis (DIN 517 18/19/20)
  - Particle shape (CAMSIZER)
  - Reactivity (reference thermobalance, 1bar CO₂, 800-1000°C)

- Challenges:
  - Hypothesis: „each particle is different“ (Influence of feedstock)
  - Non-destructive analysis methods (difficult / impossible)
  - Ultimate- and proximate analysis of the same particle: impossible
    - Ultimate analysis according to DIN
    - Proximate analysis in accordance with DIN
Results and discussion

Feedstock characterization – single-particles

Central German lignite (lignite I; x=0.5-3.0 mm)

Hard coal (x=1.6-2.0 mm)

Ultimate analysis

Proximate analysis
Results and discussion – feedstock characterization

Reactivity – single-particles

Reactivity index $R$ [1/h]

- BK3037
- BK2820
- SK3010

Reaction rate $r$ [1/s]

- SK3010
- BK3037
- BK2820

Carbon conversion $X_c = 50\%$

Reaction rate $r$

\[ r = \frac{1}{m_{C,0}} \cdot \frac{dm_C}{dt} = \frac{dX_C}{dt} \]

Reactivity index $R_S$ (Carbon conversion $X_c = 50\%$):

\[ R_S^{0.5} = \frac{0.5}{t_{1/2}} \]

Influence of feedstock

- Lignite I
- Lignite II
- Hard coal
Results and discussion – *single-particle reactions*

**Single-particle reactions in HITECOM reactor (I)**

Lignite I (T=1000 °C, p=1.0 bar CO₂)  
Hard coal (T=1000 °C, p=1.0 bar CO₂)
Results and discussion – single-particle reactions

Single-particle reactions in HITECOM reactor (II)

Lignite II (T=1000 °C, p=1.0 bar CO₂)
Results and discussion – single-particle reactions

Single-particle reactions in HITECOM reactor (II)

- Performing single-particle gasification is possible
- Determination of kinetic parameters
Validating the HITECOM results – experimental design

- Preliminary tests using reference thermobalance
  - Characterization of single-particles (lignite and hard coal)
  - Characterization of powdered samples (homogeneous)
  - Ceramic crucible (particle container, 10µl)
  - Experimental conditions:
    - Temperature range: 800-1000 °C (50K-steps)
    - Pressure: 1bar CO₂

- Experiments in HITECOM-reactor
  - Characterization of single-particles (lignite and hard coal)
  - Adhesive-fixation (hanging)
  - Experimental conditions:
    - Temperature range: 800-1000°C (50K-steps)
    - Pressure: 1bar CO₂

- Comparison of the results
Results and discussion – single-particle reactions

Validating the HITECOM results – determination of kinetic parameters

Temperature range: 800-1000 °C

- Determination of kinetic parameters successful (Arrhenius plot)
- Validation with data from the reference thermobalance successful
- Influence of the feedstock confirmed
  ➢ Possible solution: synthetic particles
Results and discussion – single-particle reactions

Further results – synthetic particles

- **Idea**: Minimization the influence of the feedstock with „ideal“ particles
  - Known and homogeneous composition
  - Known (ideal) particle shape
  - Known reactivity

- Known and well defined properties
- Comparative measurements

Synthetic particle (T=1000 °C, p=1.0 bar CO₂)
Results and discussion – *single-particle reactions*

**Further results – thermal camera**

- **Task**: Integration of the thermal camera in the HITECOM reactor
  - Calibration of the thermal camera under real conditions
  - Visual observation of single-particles during gasification

  - Temperature map on the particle surface under gasification conditions
  - Compare with simulation

Lignite I (T=1050 °C, p=1.0 bar CO$_2$)
5. Conclusion / Outlook
Conclusion

• Development, construction and commissioning of the HITECOM-Reactor finished
  • Software and hardware improvements

• Integration of particle holder into the TG
  • Further development of the particle holder / adhesive composition
  • Combination of the particle holder with TG interface

• Performing single-particle gasification is possible
  • Adjustment to models is possible

• Determination of kinetic parameters
  • Validation with data from the reference thermobalance successful

• Influence of feedstock not negligible!
  • the differences in reactivity between particles from the hard coal are larger than the
differences between particles of two central German brown coals
  • „each particle is different“

• “Avoid” the influence of the feedstock
  • Possible solution: synthetic particles
Experimental investigation of single-particle gasification

Outlook

- Expansion of the experimental design (CO₂-gasification)
  - Test other single-particle holder (e.g. ceramic-fixation)
  - Variation of the flow conditions
  - Variation of the pressure conditions (partial pressure / total pressure)
    ➢ Expanding applicability of kinetic parameters

- Investigation of the influence of the adhesive

- Water steam gasification
Thank you for your attention

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