Experimental Investigation of Solid Fuel Gasification in Entrained Flow Reactors

M. Sc. Markus Steibel¹, M. Sc. Federico Botteghi¹, Prof. Hartmut Spliethoff¹,²
¹Institute for Energy Systems, TU Munich, Germany,
²Bavarian Center for Applied Energy Research (ZAE Bayern), Germany

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## Agenda

1. **Motivation**
2. **Experimental Procedure**
3. **Experimental Equipment**
   - Pressurized High Temperature Entrained Flow Reactor (PiTER)
   - Baby High Temperature Entrained Flow Reactor (BabiTER)
   - High Pressure Thermogravimetric Analyzer (PTGA)
4. **Results**
5. **Conclusion and Future Aspect**
1 Motivation

Experimental Investigation of the Gasification of a Lignite:

Lignite gasification:
- High lignite coal resources in Germany
- High reactivity
- Low ash content
- Low costs

High Interest in Characterization of the Devolatilization and Gasification Behavior of Lignite in Entrained Flow Reactors

Investigation of the influence of
- Residence time
- Temperature
- Partial pressure of the gasification agent
- Total pressure

on the overall conversion, surface area development and reactivity of the char
2 Experimental Procedure

Fuel Characterization: German Lignite

<table>
<thead>
<tr>
<th>Proximate Analysis (a.d.)</th>
<th>Ultimate Analysis (d.a.f.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash-Content</td>
<td>Carbon</td>
</tr>
<tr>
<td>Volatiles Content</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Moisture</td>
<td>Sulfur</td>
</tr>
<tr>
<td>5.8 %</td>
<td>63.4 %</td>
</tr>
<tr>
<td>52.9 %</td>
<td>4.8 %</td>
</tr>
<tr>
<td>41.3 %</td>
<td>0.6 %</td>
</tr>
<tr>
<td>10.7 %</td>
<td>0.7 %</td>
</tr>
</tbody>
</table>

Entrained Flow Reactors

<table>
<thead>
<tr>
<th>PiTER</th>
<th>BabiTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devolatilization and Gasification Experiments</td>
<td></td>
</tr>
</tbody>
</table>

Char Sample

Lab Analysis
- Proximate and Ultimate Analysis
- Surface Area Measurement

Thermogravimetric Analyzers
- Char gasification kinetics
- Pressure, temperature, gasification agents
3 Experimental Equipment

Pressurized High Temperature Entrained Flow Reactor (PiTER)

Technical Data

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification Agents</td>
<td>Ar, N₂, O₂, CO₂, H₂O</td>
</tr>
<tr>
<td>Max. Temperature</td>
<td>1800 °C</td>
</tr>
<tr>
<td>Max. Pressure</td>
<td>5.0 MPa</td>
</tr>
</tbody>
</table>
| Steady Operation         | 1600°C, 2.0 MPa  
                          | 1200°C, 4.0 MPa  |
3 Experimental Equipment

Baby High Temperature Entrained Flow Reactor (BabiTER)

Technical Data

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Gasification Agents</td>
<td>Ar, N₂, O₂, CO₂, H₂O</td>
</tr>
<tr>
<td>Max. Temperature</td>
<td>1600°C</td>
</tr>
<tr>
<td>Pressure</td>
<td>Atmospheric</td>
</tr>
<tr>
<td>Optical Ports</td>
<td>• ELIF</td>
</tr>
<tr>
<td></td>
<td>• 2-color pyrometer</td>
</tr>
<tr>
<td></td>
<td>• FTIR</td>
</tr>
</tbody>
</table>
3 Experimental Equipment

Thermogravimetric Analyzer

**Technical Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification agents</td>
<td>Ar, N₂, O₂, H₂, CO₂, H₂O, CO</td>
</tr>
<tr>
<td>max. Temperature</td>
<td>1000°C</td>
</tr>
<tr>
<td>max. Pressure</td>
<td>5.0 MPa</td>
</tr>
<tr>
<td>Up to 100 % vol. of gasification agent concentration</td>
<td></td>
</tr>
</tbody>
</table>

Up to 100 % vol. of gasification agent concentration
4 Results

Entrained Flow Experiment Matrix:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PiTER</td>
<td>Pyrolysis</td>
<td>1200</td>
<td>0.5, 1.0, 2.0</td>
<td>Inert</td>
<td>0.3-1.4</td>
</tr>
<tr>
<td></td>
<td>Integral-Gasification</td>
<td>1200</td>
<td>0.5, 1.0, 2.0</td>
<td>O/C=1</td>
<td>0.8-2.1</td>
</tr>
<tr>
<td></td>
<td>$H_2O$-Gasification</td>
<td>1200</td>
<td>0.5, 1.0, 2.0</td>
<td>$p(H_2O) = 0.07$</td>
<td>0.8-2.1</td>
</tr>
<tr>
<td></td>
<td>$CO_2$-Gasification</td>
<td>1200</td>
<td>0.5, 1.0, 2.0</td>
<td>$p(CO_2) = 0.03; 0.07; 0.13$</td>
<td>0.8-2.1</td>
</tr>
<tr>
<td>BabiTER</td>
<td>Pyrolysis</td>
<td>1000, 1200, 1400, 1600</td>
<td>0.1</td>
<td>Inert</td>
<td>0.2-1.1</td>
</tr>
</tbody>
</table>

Evaluation: Ash-Tracer-Method

Thermogravimetric Experiment Matrix:

<table>
<thead>
<tr>
<th>Total Pressure [MPa]</th>
<th>Temperature [°C]</th>
<th>Gasification Agent [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5; 1.0; 2.0</td>
<td>750; 800; 850</td>
<td>$CO_2$: 0.12; 0.25; 0.5</td>
</tr>
<tr>
<td>0.5</td>
<td>800</td>
<td>Combined Gasification</td>
</tr>
</tbody>
</table>

Evaluation:

\[ r_{observed}(X, T, p_i) = S(X) \cdot r_{int}(T) \cdot p_i^n \]
4 Results

Pyrolysis Experiments at Different Pressures (PiTER, T=1200°C)

- No pressure effect on overall conversion
- Volatile yield levels off at larger residence times

- Surface area decreases with conversion
- Slight positive pressure effect on surface area
4 Results

Pyrolysis Experiments at Different Temperatures (BabiTER)

- Positive effect of temperature (the higher the temperature, the higher the overall conversion)
- Over 1400 °C, the positive effect is no more observable

- Surface area decreases with conversion
- Temperature effect not clear
4 Results

Integral and H$_2$O-Gasification (PiTER, T=1200°C)

- An initial impact of total pressure on conversion is detected
- At higher residence times, no total pressure effect on the overall conversion

- Lower conversion level than integral gasification at shorter residence times
- Effect of the total pressure is unclear
4 Results

**CO₂-Gasification (PiTER, T=1200°C)**

- Lowest conversion levels
- Effect of total pressure unclear, but analog to H₂O-gasification

- Clear positive effect of reactant partial pressure
- At lower residence times, similar conversion levels

**CO₂-Gasification: Overall Conversion**

1. **(1200°C, p(CO₂) = 0.03 MPa)**
   - 0.5 MPa
   - 1.0 MPa
   - 2.0 MPa

2. **(1200°C, 1.0 MPa)**
   - p(CO2) = 0.03 MPa
   - p(CO2) = 0.07 MPa
   - p(CO2) = 0.13 MPa
4 Results

Thermogravimetric Analysis: CO$_2$-Gasification

- The higher the temperature, the higher the carbon conversion
- The higher the partial pressure, the higher the carbon conversion

<table>
<thead>
<tr>
<th>Pressure [MPa]</th>
<th>Activation Energy [kJ/mol]</th>
<th>Reaction Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>$E_A = 153$</td>
<td>$n = 0.23$</td>
</tr>
<tr>
<td>1.0</td>
<td>$E_A = 158$</td>
<td>$n = 0.15$</td>
</tr>
<tr>
<td>2.0</td>
<td>$E_A = 168$</td>
<td>-</td>
</tr>
</tbody>
</table>
**4 Results**

**Thermogravimetric Analysis: Combined Gasification**

**Inhibition**
- $\text{CO}_2$ more reactive than $\text{H}_2\text{O}$
- Combined Gasification is less reactive than sole $\text{H}_2\text{O}$-gasification

**No Interaction**
- $\text{CO}_2$ and $\text{H}_2\text{O}$ react independently

**Synergy**
- Combined Gasification is more reactive than sole $\text{CO}_2$-gasification

Inhibition of the $\text{H}_2\text{O}$ gasification in the presence of $\text{CO}_2$

**Influence of the $\text{CO}_2$-content in the mixture on the reactivity**

- $r_{\text{combi}} < r_{\text{CO}_2} + r_{\text{H}_2\text{O}}$
- $r_{\text{combi}} = r_{\text{CO}_2} + r_{\text{H}_2\text{O}}$
- $r_{\text{combi}} > r_{\text{CO}_2} + r_{\text{H}_2\text{O}}$

**Graph:**
- $r(X = 30\%)$ vs. $p(\text{CO}_2)$ [MPa]
- Data points for different $p(\text{H}_2\text{O})$ pressures:
  - 0 MPa H2O
  - 0.125 MPa H2O
  - 0.25 MPa H2O

H2O-Gasification more reactive than CO2-Gasification

Combined Gasification is less reactive than sole H2O-gasification
5 Conclusion and Future Aspects

Conclusion

- Investigation of the influence of high temperature (up to 1600°C), high pressure (up to 2.0 MPa) and residence time on the devolatilization behavior and reactivity of a German lignite
- Investigation of the influence of high temperature (up to 1600°C), high pressure (up to 2.0 MPa), residence time and gasification agents (O₂, CO₂, H₂O, H₂O/CO₂) on the gasification behavior of a German lignite

  Obtained data can be used for designing large scale applications

Future Aspects

- Use kinetic parameters in an effectiveness factor approach
- Validate the model with data of the entrained flow reactors
Thank you for your Attention!

M. Sc. Markus Steibel
markus.steibel@tum.de
+49 (0) 89 287 16341
Lehrstuhl für Energiesysteme
Technische Universität München

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