Sorption Enhanced Gasification: Process validation and investigations on the syngas composition in a 200 kW$_{th}$ dual fluidized bed facility

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Motivation: Reduction of CO₂ emissions
Substitution of fossil fuels by liquid biofuels

- Dimethyl ether (DME):
  - Can be used in diesel engines with minor modifications
  - Simple handling and storage requirements
  - Clean combustion behaviour

- FLEDGED project: Novel biomass to DME process

\[ M = \frac{y_{H_2} - y_{CO_2}}{y_{CO} + y_{CO_2}} = 2 \]
Sorption Enhanced Gasification (SEG) Process
Introduction to the SEG process

**Gasifier/Carbonator**
- **Carbonation:**
  \[ \text{CaO} + \text{CO}_2 \rightarrow \text{CaCO}_3 \quad \Delta h_R < 0 \]
- **Water-gas-shift**
  \[ \text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2 \quad \Delta h_R < 0 \]

**Combustor/Calciner**
- **Calcination:**
  \[ \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \quad \Delta h_R > 0 \]
- **Char combustion**
  \[ \text{C} + \text{O}_2 \rightarrow \text{CO}_2 \quad \Delta h_R < 0 \]
SEG process
CaO/CaCO₃ equilibrium

Calculated based on: Limestone Calcination Nearby Equilibrium: Kinetics, CaO Crystal Structure, Sintering and Reactivity
The Journal of Physical Chemistry C 2015 119 (4), 1623-1641, DOI: 10.1021/jp508745u
**SEG process**

Properties and influencing parameters

- Production of a $N_2$ free syngas: no oxygen or external heating needed
- Adjustment of the C/H content in the syngas by $CO_2$ absorption
  - Syngas composition can be modified for different downstream synthesis processes
- Low tar contents in the syngas due to catalytic effect of CaO
- Low sulfur contents in the syngas (gasifier) and flue gas (calciner) due to sulfur capture by CaO

- Influencing parameters:
  - Biomass
  - Gasification temperature
  - Steam-to-Carbon ratio (S/C)
  - Looping ratio
  - …
Experimental setup
Experimental setup
200 kW\textsubscript{th} SEG Pilot Plant

<table>
<thead>
<tr>
<th>Gasifier/ Carbonator</th>
<th>Combustor/ Calciner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor height</td>
<td>6 m</td>
</tr>
<tr>
<td>Reactor diameter</td>
<td>0.33 m</td>
</tr>
<tr>
<td>Gas velocity</td>
<td>0.5 – 1.5 m/s</td>
</tr>
<tr>
<td>Reactor height</td>
<td>10 m</td>
</tr>
<tr>
<td>Reactor diameter</td>
<td>0.21 m</td>
</tr>
<tr>
<td>Gas velocity</td>
<td>3.5 – 6 m/s</td>
</tr>
</tbody>
</table>

- **Bubbling fluidized bed**
  - No external heating
  - Temperature controlled by solid looping rate
  - Solid circulation rate is adjusted by a screw conveyor

- **Circulating fluidized bed**
  - No external heating
  - Temperature controlled by combustion of biomass and char particles from the gasifier
Experimental setup

Biomass and bed material composition

• Biomass: wood pellets

<table>
<thead>
<tr>
<th></th>
<th>$H_u$</th>
<th>$Y_{H2O}$</th>
<th>$Y_{ash}$</th>
<th>$Y_V$</th>
<th>$Y_{FC}$</th>
<th>$Y_C$</th>
<th>$Y_H$</th>
<th>$Y_N$</th>
<th>$Y_S$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>J/g,ad</td>
<td>wt%,ad</td>
<td>wt%,db</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood pellets</td>
<td>17358</td>
<td>6.0</td>
<td>0.2</td>
<td>82.7</td>
<td>17.3</td>
<td>50.8</td>
<td>6.1</td>
<td>0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

$H_u$ – net calorific value  
$Y$ – mass fraction in the fuel  
$V$ – volatiles  
$FC$ – fixed carbon  
ad – air dried  
db – dry basis  
daf – dry ash free

• Bed material: German limestone ($d_p = 100 – 300 \, \mu m$)

<table>
<thead>
<tr>
<th></th>
<th>$x_{CaO}$</th>
<th>$x_{MgO}$</th>
<th>$x_{SiO2}$</th>
<th>$x_{Al2O3}$</th>
<th>$x_{others}$</th>
<th>$x_{CO2}^{2)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>wt%, db</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>German limestone$^{1)}$</td>
<td>55.4</td>
<td>0.7</td>
<td>0.4</td>
<td>0.1</td>
<td>0.2</td>
<td>43.7</td>
</tr>
</tbody>
</table>

1) Limestone analysis is not normalized to 100%
2) Mass fraction of $CO_2$ that is released as $CO_2$ during calcination
Experimental setup

Experimental parameters

- Biomass: wood pellets
- Bed material: German limestone ($d_p = 100 – 300 \, \mu m$)
- Gasification temperature $\vartheta_{\text{Gasification}}$: 600 – 774 °C
  - controlled by transfer mass flow between Calciner and Gasifier
  - syngas composition not only influenced by gasifier temperature, but also by the sorbent looping ratio
- Calcination temperature $\vartheta_{\text{Calcination}}$: 910 – 935 °C
- Steam-to-Carbon-ratio $S/C$: 1.5 mol$_{H2O}$/mol$_C$
- Steady state conditions at each experimental point: 1 – 3 h
Experimental results
Experimental results
Trends of temperatures and syngas composition

- Stable operation of the gasifier and calciner could be demonstrated
- Syngas composition at a gasification temperature of 757 °C:
  \[ y_{H2} = 62 \text{ vol}\%_{wf} \quad y_{CO} = 13 \text{ vol}\%_{wf} \quad y_{CO2} = 13 \text{ vol}\%_{wf} \]
  \[ y_{CH4} = 10 \text{ vol}\%_{wf} \quad y_{CxHy} = 2 \text{ vol}\%_{wf} \]

Fuel: wood pellets
Bed material: limestone
S/C molar ratio: 1.5
Gasification temperature: 757±8 °C
Calcination temperature: 919±8 °C
**Experimental results**

**Gas concentrations and M-module vs. gasification temperature**

- Increasing gasification temperature:
  - \( y_{H2} \downarrow \quad y_{CO} \uparrow \quad y_{CO2} \uparrow \)
  - M-module \( \downarrow \)
  - due to \( \text{CaCO}_3/\text{CaO} \) – equilibrium

- gasification temperature of about 757 °C is needed for \( M = 2 \)

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**Fuel:** wood pellets  
**Bed material:** limestone  
**S/C molar ratio:** 1.5  
**Gasification ratio:** 600 - 774 °C  
**Calcination temperature:** 910 - 935 °C
Summary and conclusion
Summary and conclusion

• Process can be operated at stable conditions in a 200 kW\textsubscript{th} DFB pilot scale facility with flexible variation of the gasification temperature between 600 and 774 °C

• Syngas composition/ M-module is strongly influenced by gasification temperature
  - due to the temperature dependency of the CaCO\textsubscript{3}/CaO equilibrium
  - SEG is very flexible in regard to the adjustment of the syngas composition for a subsequent synthesis process

• Gasification temperature of about 757 °C is needed for M = 2
  - suitable for production of DME by sorption enhanced DME synthesis process
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Thank you!

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