Ash agglomeration in the modified COORVED gasifier

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Session 4: Gasifier Developments
Outline

I. Background & motivation

II. Experimental setup & investigation

III. Results
   ▪ Limits of lignite coke gasification
   ▪ German lignite gasification with $O_2/CO_2$ and $O_2/H_2O$
   ▪ Ash-agglomeration

IV. Summary & future prospects
I. Background & Motivation

**INCI-gasification principle**

- **Internal Circulation**
- Gasification of high ash coal fines
- No slagging
- Ash agglomeration
- Reduced carbon loss via fly ash and bottom product
- Prolonged residence time to increase carbon conversion
- Target outlet temperature 1000-1100°C

**CFB flow principle**

- Strand formation
- Internal circulation

**Jetting fluidized bed**

- Prim. gasific. agent (boxer arrangement)
- Central flame (T > 2000 °C)
- Recirculation cells (internal circulation)
- Walls are protected from temperatures
- Agglomeration

**Bubbling fluidized bed**

- Internal separation mechanism
- Internal heat reuse

**Fixed bed**

- Secondary gasification agent
- Post gasification (C-content < 5%)
- Internal heat reuse
- Determines base fluidization velocity in dense fluidized bed

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Patent: DE 10 2007 006981 B4 2009.01.29
I. Background & Motivation

**COORVED-Project**

- **CO$_2$-Reduktion durch innovatives Vergaserdesign**
- CO$_2$-reduction by innovative gasifier design
- Experimental part (COORVED gasifier)
- Inverse flame research
- Simulation of gasifiers
- Funded by BMWi and Pörner Group
II. Experimental setup & investigation

COORVED lab scale unit (original design until 2014)

<table>
<thead>
<tr>
<th>Limitations</th>
<th>Achievements</th>
<th>Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparably high base fluidization for safety reasons</td>
<td>Carbon conversion of 86% in gasification of German lignite coke</td>
<td>Insufficient carbon conversion</td>
</tr>
<tr>
<td>Short residence times</td>
<td></td>
<td>No Agglomeration</td>
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<tr>
<td>Temperature increase to support conversion up to 1300°C</td>
<td></td>
<td>Slagging tendencies and wall deposits</td>
</tr>
<tr>
<td>Risk of slagging and ash deposits at walls</td>
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</tbody>
</table>

1 bar(a); ≤ 100 kW; Øₗ = 0.15 m; H = 6 m  
23 campaigns  
250 operating hours
II. Experimental setup & investigation

**COORVED lab scale unit (new design since 2015)**

**Modifications**

- Diameter in bottom section decreased  
  → Reduction of required gas flow rate
- Diameter in main reaction zone increased  
  → Reduced flow velocity
- Conical widening (60°)
- Central part with refractory lining
- Improved pre-heating by gas burner

**Achievements**

- Reduced max. wall temperatures
- Formation of a spouted bed  
  → Increased C-holdup  
  → Increased residence time
- Stabilized operation and improved controllability

1 bar(a); ≤ 60 kW  
Ø=0.10–0.30m; H=6m

21 campaigns  
280 operating hours
III. Results

Comparison of both designs - lignite coke gasification

Achievements
- Carbon conversion $X_C > 93\%$ (7 %↗)
- $\Delta T_{\text{Wall,max.}} = -150\ldots-250$ K

Limitations
- Coke with low reactivity
  - Increased oxygen addition ($\lambda$↗)
  - Enlarged hot central zone ($T_{\text{avg.}}$↗)
- Missing volatile matter
  - Difficult temperature control
- No ash agglomeration!

Possible solution:
Lignite gasification

\begin{figure}[h!]
\centering
\includegraphics[width=\textwidth]{comparison_diagram.png}
\end{figure}

\begin{itemize}
\item O$_2$/CO$_2$ o.d.
\item O$_2$/H$_2$O o.d.
\item O$_2$/CO$_2$/H$_2$O o.d.
\item O$_2$/CO$_2$ n.d.
\item O$_2$/H$_2$O n.d.
\item O$_2$/CO$_2$/H$_2$O n.d.
\end{itemize}
### III. Results

**German lignite gasification with O₂/CO₂ and O₂/H₂O**

#### Operation without ash agglomeration

<table>
<thead>
<tr>
<th>Settings</th>
<th>Achievements</th>
<th>Issues / Findings</th>
</tr>
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<tbody>
<tr>
<td><strong>O₂/CO₂</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total air ratio ≈ 0.4</td>
<td>Xc &gt; 93 %</td>
<td>No ash agglomeration</td>
</tr>
<tr>
<td>CO₂/O₂ ≈ 1.8 kg/m³ (STP)</td>
<td>η&lt;sub&gt;CGE&lt;/sub&gt; &gt; 60 %</td>
<td></td>
</tr>
<tr>
<td>T&lt;sub&gt;MRZ&lt;/sub&gt; ≈ 1200 °C</td>
<td>Syngas-yield: 1.4 m³/kg (STP/waf)</td>
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<tr>
<td><strong>Ash agglomerating operation</strong></td>
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<tr>
<td><strong>O₂/CO₂</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total air ratio ≈ 0.5</td>
<td>Xc &gt; 96 %</td>
<td>High temperature</td>
</tr>
<tr>
<td>CO₂/O₂ ≈ 2.1 kg/m³ (STP)</td>
<td>η&lt;sub&gt;CGE&lt;/sub&gt; &gt; 55 %</td>
<td>Ash agglomeration</td>
</tr>
<tr>
<td>T&lt;sub&gt;MRZ&lt;/sub&gt; ≈ 1300 °C</td>
<td>Syngas-yield: 1.3 m³/kg (STP/waf)</td>
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<td></td>
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<tr>
<td><strong>O₂/H₂O</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total air ratio ≈ 0.4</td>
<td>Xc &gt; 92 %</td>
<td>Lower temperature</td>
</tr>
<tr>
<td>H₂O/O₂ ≈ 1.2 km³/m³ (STP)</td>
<td>η&lt;sub&gt;CGE&lt;/sub&gt; &gt; 54 %</td>
<td>Ash agglomeration</td>
</tr>
<tr>
<td>T&lt;sub&gt;MRZ&lt;/sub&gt; ≈ 1200 °C</td>
<td>Syngas-yield: 1.5 m³/kg (STP/waf)</td>
<td></td>
</tr>
</tbody>
</table>

**Settings**

- Total air ratio ≈ 0.4
- CO₂/O₂ ≈ 1.8 kg/m³ (STP)
- T<sub>MRZ</sub> ≈ 1200 °C

**Achievements**

- Xc > 93 %
- η<sub>CGE</sub> > 60 %
- Syngas-yield: 1.4 m³/kg (STP/waf)

**Issues / Findings**

- No ash agglomeration

Note for low η<sub>CGE</sub>:
- Heat losses ≈ 25 % of thermal input!
III. Results

Exemplary results: German lignite gasification with $O_2/H_2O$

**Coal**
Thermal Input: 51.6 kW

**Coal ash (815°C)**
- Ash Content: 7 wt.% (wf)

**Composition**
- $Fe_2O_3$: 26.8 wt.%
- CaO: 25.2 wt.%
- MgO: 9.9 wt.%
- $SiO_2$: 9.4 wt.%
- $Al_2O_3$: 4.3 wt.%

**Ash melting (red. atmosph.)**
- Init. deform. temp.: 1300°C
- Spherical temp.: 1318°C
- Hemisph. temp.: 1396°C
- Fusion temp.: 1510°C

**Raw gas:** 16.8 m³(STP)/h (wf)
- $H_2$: 29.9 vol.%
- CO: 29.9 vol.%
- $CH_4$: 0.1 vol.%
- $CO_2$: 34.2 vol.%
- $N_2$: 5.9 vol.% (Purging gas)
- **Gas free of tars and oils!**

**Agglomerates**
- Ash Content: > 99 wt.%

**Composition**
- $Fe_2O_3$: 19.5 wt.%
- CaO: 36.0 wt.%
- MgO: 15.3 wt.%
- $SiO_2$: 12.8 wt.%
- $Al_2O_3$: 4.8 wt.%
- $SO_3$: 4.8 wt.%

**Ash melting (red. atmosphere)**
- Init. deform. temp.: 1290°C
- Spherical temp.: 1300°C
- Hemisph. temp.: 1373°C
- Fusion temp.: 1514°C
III. Results

Ash agglomerates of German lignite - gasification with O$_2$/CO$_2$ and O$_2$/H$_2$O

- x(C) < 1 wt.%
- Molten surface → Low permeability → Risk of slagging
- x(C) < 1 wt.%
- Porous surface
IV. Summary & future prospects

**INCI – gasifier COORVED**
- Optimized reactor design
- Improved operability

**Experimental findings**
- Reduced max. wall temperatures
- Increased residence time
- Increased carbon conversion
- Low coke reactivity unfavorable for agglomeration
- Ash agglomeration for lignite gasification
- Controlled ash agglomeration in $O_2/CO_2$- and $O_2/H_2O$-atmospheres
- Efficient agglomerate post-gasification
- Tar- and oil-free raw gas

**INCI – gasifier COORVED**
- Further reactor design optimization
- Changes in moving bed zone (Secondary gas nozzles, pre-heating, diameter)
  → Improved post-gasification for feedstocks with higher percentage of coarse grain and ash
- Varied solids feeding position

**Demanding Feedstocks**
- Lignite with higher ash content
- High ash hard coal
The End

Thank you for your attention!

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