Modeling-based Evaluation of Gasification Processes for High-Ash Coals

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Outline

1. Trends in coal gasification development
2. Approach of this study
3. Results
   • The influence of ash content
   • Exergetic analysis
4. Conclusion
1 – Trends in coal gasification development

Available Gasification Technologies

1 – Trends in coal gasification development

**New concepts for traditional technologies**

- **Shell** – partial water quench
- **Prenflo** – full water quench
- **Phillips 66** – E-STR Entrained slagging transport reactor
- **GE** – posimetric feeding system
- **Lurgi/AL** – Mark+
- **Siemens** – radiant cooler

**New concepts**

- **INCI** – internal circulating gasifier
- **PWR** – compact gasifier
- etc.

1 – Trends in coal gasification development

**Overview on technology development drivers**

- **Reduction of capital costs**
  - Increase in single unit capacity
  - Increase in gasification pressure

- **Inclusion of full water quench in portfolio**
- **Integration of dry feed solid pumps**

- **Inclusion of syngas cooler in portfolio**
- **Increase in efficiency**
  - Migration from slurry to dry feeding or slurry drying
  - Increase in single-pass carbon conversion

- **Adaptation to low-grade feedstock**
  - GE
  - Siemens
  - P66
  - Prenflo
  - Shell

- **Increase in gasification pressure**

- **New concepts**
  - INCI
  - P66
2 – Approach of this study

Results of generic modeling

Results of adiabatic equilibrium calculations (30 bar)

Temperature & carbon conversion

Cold gas efficiency & dry CH₄ yield

Syngas yield & H₂/CO ratio

Selectivity of CO/C & CH₄/C

2 – Approach of this study

Unified boundary conditions for gasifier modeling

<table>
<thead>
<tr>
<th>Coal (abbreviation)</th>
<th>South Africa</th>
<th>Pittsburgh #8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal rank (ASTM [8])</td>
<td>HV C Bit.</td>
<td>HV A Bit.</td>
</tr>
<tr>
<td>Moisture wt%</td>
<td>6.0</td>
<td>2.4</td>
</tr>
<tr>
<td>Proximate analysis (dry basis)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash wt%</td>
<td>25.0</td>
<td>10.2</td>
</tr>
<tr>
<td>Volatiles wt%</td>
<td>23.0</td>
<td>36.1</td>
</tr>
<tr>
<td>Fixed carbon wt%</td>
<td>52.0</td>
<td>53.7</td>
</tr>
<tr>
<td>Ultimate analysis (dry &amp; ash free basis)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon wt%</td>
<td>80.0</td>
<td>83.3</td>
</tr>
<tr>
<td>Hydrogen wt%</td>
<td>4.0</td>
<td>5.7</td>
</tr>
<tr>
<td>Oxygen wt%</td>
<td>13.0</td>
<td>8.3</td>
</tr>
<tr>
<td>Nitrogen wt%</td>
<td>2.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Sulphur wt%</td>
<td>1.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Calorific Value (dry basis)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Heating Value MJ/kg</td>
<td>21.9</td>
<td>31.5</td>
</tr>
</tbody>
</table>

Technology | Verification data
-----------|--------------------
Shell      | Rich et al. [9]
Siemens   | Babcock [10]
GE        | McDaniel [11]
Phillips 66 | Woods et al. [12]
HTW       | Bellin et al. [13]

Exergy reference environment:

- $T_0 = 25°C$, $p_0 = 1013.25$ hPa
- Water is in the liquid state.
- Dry atmosphere: 78.1 vol% $N_2$, 21.0 vol% $O_2$ and 0.9 vol% Ar
- Chemical exergies of substances containing C, S and N are in inhibited equilibrium with the environment in their oxidized state ($CO_2$, $SO_2$, NO).

## Unified boundary conditions for gasifier modeling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comment / Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>30 bar</td>
<td>Suitable for IGCC and several syntheses</td>
</tr>
<tr>
<td>Temperature</td>
<td>1550/1450 °C</td>
<td>&gt; 100 K above ash fluid temperature for slagging systems</td>
</tr>
<tr>
<td>Thermal capacity</td>
<td>500 MW</td>
<td>Coal input on LHV basis</td>
</tr>
<tr>
<td>Coal/N₂ temperature</td>
<td>25 °C</td>
<td>N₂: 99.96 %vol purity, +3 bar above reactor</td>
</tr>
<tr>
<td>Coal/transport gas</td>
<td>350 kg/m³(eff.)</td>
<td>Higman and van der Burgt [14], Schingnitz [15]</td>
</tr>
<tr>
<td>Solids in slurry</td>
<td>65 %wt</td>
<td>Hornick and McDaniel [16]</td>
</tr>
<tr>
<td>Slurry temperature</td>
<td>120 °C</td>
<td>Valenti [17]</td>
</tr>
<tr>
<td>O₂ purity</td>
<td>95 %vol</td>
<td>Residual: 3 %vol Ar, 2 %vol N₂</td>
</tr>
<tr>
<td>O₂ temperature</td>
<td>240 °C</td>
<td>+3 bar above reactor</td>
</tr>
<tr>
<td>Moderator steam</td>
<td>37 bar / 246 °C</td>
<td>Saturated</td>
</tr>
<tr>
<td>Quench water</td>
<td>37 bar / 175 °C</td>
<td>Preheating for high raw gas moisture</td>
</tr>
<tr>
<td>IP steam</td>
<td>37 bar / 246 °C</td>
<td>No superheating</td>
</tr>
<tr>
<td>HP steam</td>
<td>140 bar / 377 °C</td>
<td>von Morstein et al. [18]</td>
</tr>
</tbody>
</table>

3 – Results: Understanding the influence of ash content

**Cold gas efficiency (CGE)**

- Operation area, where CGE > 80%, becomes smaller and shifts below ash fluid temperature with increasing ash content.

\[ \eta_{CGE} = \frac{m_{gas} \cdot LHV_{gas}}{m_{coal} \cdot LHV_{coal}} \cdot 100\% \]

- Single-stage slagging gasifiers cannot be adapted!
Cold gas efficiency (CGE)

- Slurry gasifiers are not suitable for high ash contents, dry-feed slagging system lose approx. 6 %-pts. in CGE
- Except for Siemens and Shell (only gas cooling is changed), all new concept show improvements
- Fluidized-bed processes are most independent from ash content
  → INCI concept optimal for ash contents between 15 and 35 wt%(wf)
3 – Results: Understanding the influence of ash content

**Syngas yield (SGY)**

Coal ash content in wt% (wf):
- 5.0
- 25.3
- 45.0

- Standard systems
- New concepts

\[
Y_{Syngas} = \frac{\dot{n}_H_2 + \dot{n}_CO}{\dot{m}_{coal} \cdot (1 - w - a)}
\]

- Operation area where SGY > 2 m³/kg becomes smaller and shifts significantly below ash fluid temperature with increasing ash content.

→ Again single-stage slagging gasifiers cannot be adapted!
3 – Results: Understanding the influence of ash content

**Syngas yield (SGY)**

- High SGY up to 25 wt%(wf) ash for dry-fed entrained-flow gasifiers
- Significant improvements in the new concepts of GE and INCI
- E-STR concept improves with increasing ash content
- Traditional fluidized-bed processes (HTW) operate on a lower level
- INCI concept optimal for ash contents >40 wt%(wf)
3 – Results: Exergetic analysis

Exergy losses in gas cooling (in standard designs)

- Siemens: -37.7% thermo-mechanical (tm.) exergy loss due to full water quench
- P66: chemical quench allows part of the tm. exergy to be converted to chemical exergy
- GE-R: in fouling-safe radiant cooler-only design 32.5% tm. exergy recovery by steam generation
- Shell: the cold gas quench causes an tm. exergy loss of -7.2%
- GE-RC: 51.6% of tm. exergy can be recovered employing radiant and convective syngas cooling (e.g. Polk IGCC)
3 – Results: Exergetic analysis

Understanding the influence of ash content – Syngas Yield (SGY)

- All new concept except the full water quench design from Shell lead to improved overall exergetic efficiency of the systems
- Improvements become more significant with increasing ash content of the coal
  - INCI concept has the highest potential for high-ash coals
Processing of high-ash coals (esp. fines):
→ Development of high-conversion fluid-bed gasifiers is recommended

INCI concept shows:
- Advantages in terms of cold gas efficiency at ash contents of 15-35 wt% (wf) and syngas yield at >40 wt% (wf)
- The highest exergetic efficiency of all concepts
→ highest potential for high-ash coals
End of Presentation

Thank you for your attention – Questions?

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