Pilot scale studies on CO2 enhanced gasification in pressurized fluidized bed reactor

Summary results of the Polish National Strategic Research Program

Aleksander Sobolewski, Marek Ściążko, Tomasz Chmielniak, Grzegorz Tomaszewicz, Andrzej Czaplicki, Tomasz Iluk, Krzysztof Słowik
Strategic research programme – Advanced Technologies for Energy Generation

Development of coal gasification technology for highly efficient production of fuels and electrical energy.

Research topic no 2:
Development and verification in pilot scale of technology for pressurized gasification of coal in circulating fluidized bed reactor with use of CO₂ as a gasification agent.

Coordinator: Institute for Chemical Processing of Coal

CTB no: 2.2.4:
Research on process and technological aspects of coal gasification technology based on utilization of CO₂ as gasification agent in circulating fluidized bed reactor (pilot scale research)
The goal of a part of research topic no 2.2.4 was development of background and verification in pilot scale of a technology for production of syngas with use of CO$_2$ as gasification agent, in a reactor with circulating fluidized bed.
Institute for Chemical Processing of Coal - Centre for Clean Cola Technologies (CCTW)

Technological hall no. 2 - pilot-scale atmospheric and pressurized CFB reactors

Cooling towers and Technical gas installation

Fuel preparation site

Technological hall no. 1
Bench-scale BFB reactor

...beyond standards!
Research infrastructure

Makro-lab research

Large laboratory scale:
- Bubbling fluidized bed reactor:
  - 1.5 MPa, 950°C, 2 kg/h continuous process

Pilot scale:
- Circulating fluidized bed reactor:
  - atm., 1000°C, 200 kg/h continuous process

Pilot scale research

Pilot scale:
- Circulating fluidized bed reactor:
  - 1.5MPa, 1000°C, 100 kg/h continuous process

...beyond standards!
Bubbling fluidized bed reactor:
- 75mm internal diameter,
- resistance furnace (heating up to 700°C)
- water jacket
- removable distributor
- bed sampling port
- screw feeder and drop tube for directly fuel transportation into the process bed
- pressure range 0-15 bar
- temperature range 700 – 1000°C

Gasifying agents:
$O_2$, $CO_2$, Air, Superheated steam (6 bar, 400°C)

Auxiliary equipment:
Cyclone and two stage heat exchanger
## Research infrastructure – large lab. scale

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Hard coal</th>
<th>Lignite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel stream</td>
<td>kg/h</td>
<td>2.34 – 3.27</td>
<td>2.34 – 2.77</td>
</tr>
<tr>
<td>Air to carbon ratio</td>
<td>kg/kg</td>
<td>2.89 – 3.27</td>
<td>2.14 – 3.52</td>
</tr>
<tr>
<td>CO₂ to carbon ratio</td>
<td>kg/kg</td>
<td>4.13 – 4.93</td>
<td>2.12 – 3.90</td>
</tr>
<tr>
<td>Gasification temperature</td>
<td>°C</td>
<td>863 – 928</td>
<td>776 – 865</td>
</tr>
<tr>
<td>Gasification pressure</td>
<td>bar</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Syngas composition (dry, w.o. N₂ and CO₂)</td>
<td>vol. %</td>
<td>H₂  8.9 – 15.7</td>
<td>18.3 – 30.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CH₄ 11.6 – 14.3</td>
<td>5.9 – 8.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO   42.4 – 51.3</td>
<td>41.3 – 51.9</td>
</tr>
</tbody>
</table>

...beyond standards!
Research infrastructure – pilot scale – CFB

…beyond standards!
Circulating fluidized bed reactor:
- 140 mm internal diameter,
- ceramic lining
- screw feeder transports fuel directly into the process bed
- pressure range 0-0.3 bar
- temperature range 700 – 1000°C
- bed circulation realized by the primary cyclone (4) and a dedicated screw feeder for better control of the process
- gas after throughout dedusting in secondary battery of cyclones is flared

Gasifying agents:
$O_2$, $CO_2$, air, superheated steam (6 bar, 400°C)
# Research infrastructure – pilot scale – CFB

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lignite</th>
<th>Hard coal 1</th>
<th>Hard coal 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification temperature [°C]</td>
<td>855-950</td>
<td>890-980</td>
<td>820-1000</td>
</tr>
<tr>
<td>Coal feed rate [kg/h]</td>
<td>85-130</td>
<td>125-140</td>
<td>95-140</td>
</tr>
<tr>
<td>Air stream [m³/h]</td>
<td>40-120</td>
<td>45-145</td>
<td>70-130</td>
</tr>
<tr>
<td>CO₂ stream [m³/h]</td>
<td>0-65</td>
<td>0-60</td>
<td>0-45</td>
</tr>
<tr>
<td>O₂ stream [m³/h]</td>
<td>0-20</td>
<td>0-25</td>
<td>0-10</td>
</tr>
<tr>
<td>Amount of volatile components in syngas* [vol. %]</td>
<td>up to 65</td>
<td>up to 60</td>
<td>up to 45</td>
</tr>
</tbody>
</table>

*Beyond standards!*
Research infrastructure – pilot scale – PCFB

...beyond standards!
## Results of the research programme

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lignite</th>
<th>Hard coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification temperature [°C]</td>
<td>810-950</td>
<td>890-935</td>
</tr>
<tr>
<td>Coal feed rate [kg/h]</td>
<td>15-85</td>
<td>30-40</td>
</tr>
<tr>
<td>Air stream [kg/h]</td>
<td>0-85</td>
<td>5-10</td>
</tr>
<tr>
<td>CO₂ stream [kg/h]</td>
<td>0-105</td>
<td>45-70</td>
</tr>
<tr>
<td>O₂ stream [kg/h]</td>
<td>0-35</td>
<td>10-30</td>
</tr>
<tr>
<td>Pressure, bar</td>
<td>1,3-6,2</td>
<td>1,8-2,7</td>
</tr>
<tr>
<td>Amount of volatile components in syngas * [vol. %]</td>
<td>up to 75</td>
<td>up to 60</td>
</tr>
</tbody>
</table>

* without CO₂
Results of the research programme

![Graph showing the ratio of CO/C, kg/kg, versus temperature, °C for lignite and hard coal. Lignite is represented by triangles, and hard coal by diamonds. The graph illustrates a trend beyond standards!](image-url)
Results of the research programme

Steam of CO₂, kg/h

Ratio of CO₂/C, kg/kg

Lignite
Hard coal

...beyond standards!
Results of the research programme

![Graph showing the ratio of C/CO₂, kg/kg against the ratio of CO₂/C, kg/kg.](image)

- Lignite
- Hard coal

...beyond standards!
Results of the research programme

![Graph showing the ratio of O\(_2\)/CO\(_2\), kg/kg vs. the ratio of CO\(_2\)/C, kg/kg for different types of coal: Hard coal, Hard coal, and Lignite. The graph demonstrates a decreasing trend with increasing ratio of CO\(_2\)/C.]

...beyond standards!
Summary

- Process of CO$_2$ enhanced gasification of coal in CFB, may be realized in technical scale. CO$_2$ stabilized operation of the reactor.

- Increase of gasification temperature promotes Boudouard reaction (850-950°C).

- Application of CO$_2$ effects in increased production of CO in syngas up to 40% for lignite and 30% for hard coal.

- CO$_2$ enables substitution of up to 30% of primary feedstock used in the process (coal).
Summary

- Technology of coal gasification in fluidized bed reactor with use of CO$_2$ as a gasification agent has been developed.

- Experimental theses of the project have been proven. Results of performed technological research permit for formulation of qualitative and quantitative conclusions.
Thank You Very Much