Allothermal gasification and integrated syngas cleaning by hot K$_2$CO$_3$ scrubbing for decentralized SNG production

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1. Motivation:
   - CO2freeSNG2.0 – Coal-to-SNG with integrated syngas cleaning

2. Coal/Biomass-to-SNG
   - Allothermal gasification and carbonate syngas scrubbing

3. EVT lab-scale test stands
   - 5 kW gasifier and Benfield scrubber

4. Results Gasification
   - Gasification
   - Syngas cleaning

5. Conclusion
Motivation - CO2freeSNG2.0

Project goals

- Integrated **process optimization** and economic feasibility study of medium-scale SNG plants based on process **simulations**
- Extensive lab- and **bench-scale testing** of lignite gasification with integrated CO₂ removal and catalytic methanation (5 kW Process chain)
- **Demonstration** of the complete process chain with integrated technologies:
  - 100 kW EVT-Heatpipe Reformer
  - Scrubbing unit based on Benfield process
  - Methanation with conventional and new developed catalyst systems

The research project CO2freeSNG2.0 (RFCR-CT-2013-00008) is funded by the Research Fund for Coal and Steel of the European Commission.
EVT – Heatpipe Reformer

- Allothermal steam gasification
- Dual fluidized bed reactor:
  - Atmospheric combustion
  - Pressurized gasification
  - Heat transfer by Heatpipes

- Coal
- Steam
- Raw Syngas

- Heat- Pipes
- Combustion-chamber
- Evaporation zone
- Adiabatic zone
- Condensation zone
- Vapor flow
- Liquid flow
- Mesh structure
- Heat source
- Heat sink
- Flue gas
**EVT – Heatpipe Reformer**

**Heatpipe reformer**

- **Water**
- **Raw syngas**
- **Clean syngas**
- **RME**
- **RME, tar, condensate**
- **Flue gas**
- **Primary air**
- **Gasification reactor**
- **Gasification fuel**
- **Secondary air**
- **Combustor**
- **Combustion fuel**
- **Steam**
- **Ash, char**
- **Water**

**Diagram Details**

- **Flue gas**
- **Primary air**
- **Gasification reactor**
- **Gasification fuel**
- **Secondary air**
- **Combustor**
- **Combustion fuel**
- **Steam**
- **Ash, char**
- **Water**
- **RME**
- **RME, tar, condensate**
Integrated Syngas Cleaning

Motivation

- Utilization of light hydrocarbons and tars (BTX) for methanation
- **Removal of heavy tars** to prevent coke formation
- Bulk sulfur removal necessary for catalyst life time
- Adjustment of the C/H/O-ratio by partial CO₂ removal

Approach

- Scrubbing at elevated temperature based on Benfield process
  - Condensation of heavier tars
  - Bulk removal of sulfur components
  - Removal of surplus CO₂

Application

- Bulk syngas cleaning for decentralized SNG production in small and mid scale plants
**Carbonate Scrubbing – Benfield Process**

**Homer E. Benson**  
**Joseph H. Field**

**United States Patent Office**

**2,886,405**

**METHOD FOR SEPARATING CO₂ AND H₂S FROM GAS MIXTURES**

Homer Edwin Benson and Joseph H. Field, Pittsburgh, Pa., assignors to the United States of America as represented by the Secretary of the Interior

Application February 24, 1956, Serial No. 567,692

18 Claims. (Cl. 23—3)

This invention is concerned with an improved method for removing carbon dioxide and hydrogen sulfide from gas mixtures containing either or both of these slightly acidic gases. ....

**Basic data Carbonate scrubbing**

- Increased solvent temperature
- No additional solvent cooling before absorber inlet
- Low reboiler duty (steam) necessary
- Stabile and non-toxic solvent

\[
K_2CO_3 + CO_2 + H_2O \rightleftharpoons 2 KHCO_3
\]

\[
K_2CO_3 + H_2S \rightleftharpoons KHS + KHCO_3
\]
SNG-Production – process chain 5 kW

Motivation

Gasification

Syngas Cleaning

Test stands

Results

Conclusion
SNG-Production – 5 kW Gasifier

Technical Data
- Stationary fluidized bed
- Electrical reactor heating
- Allothermal steam gasification
- Pressure: up to 6 bar
- Gasification temperature: 800 – 900 °C
- Hot gas filter
- Inspection glas

Fuel inlet
Pressure lock
SPC
Steam generator
Reactor heating

Fuel
Raw
Syngas
Steam
SNG-Production – 5 kW Scrubber

Technical Data

- $P = 5 \text{ bar}_a$, $T_{\text{Solvent}} = 100^\circ\text{C}$, 30 wt.-% $K_2\text{CO}_3$
- Packings: Raschig Rings 6 mm VA
**Results – Gasification – Temperature**

- **Syngas composition (dry, N₂-free)**
  - H₂
  - CO₂
  - CO
  - CH₄

**Biomass gasification**

\[ p = 1.3 \text{ bar}_a \]
\[ \sigma = 12 \]
Results – Gasification – Temperature

![Graph showing the results of gasification with temperature variation.](image)

Biomass gasification

\[ p = 1.3 \text{ bar}_a \]
\[ \sigma = 12 \]
Results – Gasification – Steam excess ratio

Biomass gasification
\[ p = 1.3 \text{ bar}_a \]
\[ T_{FB} = 830 \text{ °C} \]
Motivation

Results – Gasification – Steam excess ratio

Biomass gasification

\[
p = 1.3 \text{ bar, } T_{FB} = 830 \, ^\circ\text{C}
\]
Results – Gasification

Light Hydrocarbons and Sulfur

- Overall tar reduction with rising gasification temperature
- At lower gasification temperatures shift towards aromates
- Ethene and Ethine decrease with rising gasification temperature
- Sulfur compounds barely affected by fluidized bed temperature
  - H₂S
  - Thiophene

\[p = 5.2 \text{ bar}, \sigma = 3.26\]
Results – Scrubber

Removal efficiency

\[
\eta_{CO2} = \frac{(x_{CO2, raw} - x_{CO2, clean})}{(x_{CO2, raw} \times (1 - x_{CO2, clean})}
\]

\[
\eta_{H2S} = \frac{(x_{H2S, raw} - x_{H2S, clean})}{(x_{H2S, raw} \times (1 - x_{H2S, clean})}
\]

Liquid-to-Gas ratio

\[
\frac{L}{G} = \frac{\dot{m}_{Solvent}}{\dot{m}_{Syngas}}
\]

Simulation vs. bench scale tests

- Simulation of 90% CO₂ removal efficiency @ L/G 19 proofed only up to 65% in bench scale tests due to heat losses and edge effects → higher efficiency reached in pre-pilot scale
Results – Scrubber – L/G-ratio

The graph shows the CO₂ removal efficiency for different liquid-to-gas ratios (L/G) for various syngas compositions. The x-axis represents the liquid-to-gas ratio (L/G), while the y-axis shows the syngas composition in percentage terms.

- **H₂**
- **CO₂**
- **CO**
- **CH₄**

Each composition is represented by a different symbol, and the graph illustrates how the CO₂ removal efficiency changes with varying L/G ratios for raw and treated syngas.
Results – Scrubber – L/G-ratio

- Syngas tar loading [mg/Nm³]

- Gasifier
- L/G 10
- L/G 12
- L/G 14
- L/G 16
- L/G 18
- L/G 20
Results – Scrubber – Solvent

**a)** CO₂ Removal efficiency

- 10 wt.-% K₂CO₃
- 20 wt.-% K₂CO₃
- 30 wt.-% K₂CO₃ *

Liquid-to-gas ratio (L/G [-])

**b)** CO₂ Removal efficiency

- Without PZ
- 2.5 wt.-% PZ
- 5.0 wt.-% PZ

* Biomass gasification
Results – Scrubber

Tar removal

- Reduced syngas vol.-flow due to CO₂ removal
- Higher BTX concentration after scrubber but
- Less aromates after scrubber
- Close to total removal of heavier hydrocarbons ($T_B > 350 ^\circ C$)

![Graph showing tar concentration comparison between Gasifier and Scrubber](image)
100 kW Process chain

Fuel supply
Synthesis gas
Heat pipes
Heat exchanger for primary air
Refractory lining for furnace
Primary air inlet

Flue gas
Insulation
Reformer pressure vessel
Secondary air inlet
Furnace
Insulation

Desorber
Absorber
Condenser
Flash drum
Reboiler
HPR filter
Tar separator
Pre-pilot carbonate scrubber
EVT-Heatpipe Reformer

1. Deutsches Doktorandenkolloquium Bioenergie, DBFZ, September 20-21, 2018, Leipzig
100 kW Process chain – Demonstration

**Motivation**
- Gasification
- Syngas Cleaning
- Test stands

**Results**
- 100 kW Process chain – Demonstration
  - Heatpipe Reformer
  - Scrubber
  - not recorded (methanation)

**Conclusion**
- Lignite gasification
  - $p_{\text{gasifier}} = 4.0 \text{ bar}_a$
  - $p_{\text{absorber}} = 3.8 \text{ bar}_a$
  - $T_{\text{Syngas, clean}} = 120 ^\circ C$
100 kW Process chain – Demonstration

<table>
<thead>
<tr>
<th>Concentration (dry, N₂-free) [vol.-%]</th>
<th>Lignite 1.3 bar</th>
<th>Lignite 4.0 bar</th>
<th>Biomass 1.5 bar</th>
<th>Biomass 4.0 bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO</td>
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</tr>
<tr>
<td>CO₂</td>
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<tr>
<td>CH4</td>
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</tbody>
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Demonstration October 2016

pre-pilot scrubber at FAU
Conclusion

CO2freeSNG2.0
- Decentralized SNG-Production from coal or biomass with integrated syngas cleaning and CO$_2$-removal
- Bench scale testing: Gasifier, Scrubber, Methanation (5 kW)
- Demonstration of the pre-pilot scale process chain
  - Heatpipe Reformer(100 kW) + Scrubber

Allothermal steam gasification
- Steam surplus variation to support methanation
- Tar load and composition in focus of investigation

Integrated Syngas Cleaning
- Syngas scrubbing at elevated temperatures based on the Benfield process as bulk cleaning process
  - Heavy tar components (Condensation)
  - Surplus CO$_2$ und sulfur compounds removal
- Utilization of light hydrocarbons in Methanation

Thank you!