TwoStage gasification of biomass for clean syngas: Technology and applications

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TwoStage gasification of biomass for clean syngas: Technology and applications

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DTU Chemical Engineering
DTU IEC 2013 | Agenda

- Presenting The Biomass Gasification Group
- Describing TwoStage downdraft gasification technology and gas characteristics
- Examples Application of clean synthesis gas
Biomass Gasification Group | History

1987
The Beginning

1991
Halmfortet
Forsøgsområde 120

2000
DTU MEK

2007
Risø DTU

2012
DTU KT (Risø)
BGG History | History & Results

20 years of research, development and demonstration has resulted in two pre-commercial gasification processes:

1. **The TwoStage gasifier**, a high temperature process for gasification of wood (developed in cooperation with COWI)

2. **The PYRONEER gasifier** (Low Temperature Circulating Fluid Bed), a low temperature process for gasification of low grade biomass e.g. straw, manure and waste (developed in cooperation with Danish Fluid Bed Technology)
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FACILITIES
BGG Facilities | DTU Chemical Engineering (KT)
BGG Facilities | BGG at DTU KT (Risø)
BGG Facilities | Building 313

**PHYMLAB**

- Physical and mechanical testing
- Grindability
- Pelletization
- Humidification
- Drying
- Sampling
- Etc.

**CHEMLABs**

- Chemical and analytical testing
  - GC
  - HPLC
  - Extraction
  - M-TGA
  - Heating value
  - Etc.
BGG Facilities | Building 321

THERMOLAB
High temperature testing
- Macro-TGA
- Pyrolysis
- Torrefaction
- Drying
- Annealing
- Etc.

WORKSHOP
Preparation and large scale testing
- Welding
- Cutting
- Construction
- SOFC setup
- LT-CFB setup
- Etc.
Technology description

TWO-STAGE THERMAL GASIFICATION OF BIOMASS
Gasification | TwoStage Gasification
Gasification | TwoStage Gasification

The Viking TwoStage Gasifier

- Small scale fixed-bed two-stage CHP (70 kW fuel)
- Commissioned August 2002
- Fully automated and unattended operation
- 4004 (3600) hours of operation
Gasification | TwoStage Gasification

TwoStage downdraft pilot plant at Weiss A/S

VIKING 1:1

Pilot plant at Weiss A/S 1:10
Gasification | TwoStage Gasification

Up-scaling of TwoStage downdraft gasification for CHP production: Hadsund/Hillerød, Denmark

[Diagram of gasification process]

Courtesy Weiss A/S
Weiss A/S, DTU KT and COWI have designed and build a 500 kW\textsubscript{el} gasifier in the city of Hillerød.

The plant will operate as a combined heat and power plant, producing heat for households and electricity for the grid.

1000 hours of operation during commissioning
TwoStage Gasification | Perspectives

- High gasification efficiency > 93%
- High electrical efficiency >40% with gas engines
- Potential electrical efficiency ~50% with SOFC
- Ideal for decentralised combined heat and power production (CHP)
- High total efficiency (CHP mode) >100%
TwoStage Gasification | Gas characteristics

- **Permanent gas species composition:**

<table>
<thead>
<tr>
<th>Gas species</th>
<th>CO</th>
<th>CO₂</th>
<th>H₂</th>
<th>CH₄</th>
<th>N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vol%, dry</td>
<td>19.6</td>
<td>15.4</td>
<td>30.5</td>
<td>1.2</td>
<td>33.3</td>
</tr>
</tbody>
</table>

  Gas from the Viking gasifier operated on pine wood chips. Ahrenfeldt et al., 2006

- **LHV\textsubscript{gas}:** 5-6 MJ/Nm\textsuperscript{3} Ahrenfeldt et al., 2006

- **Tar content:** 0.02-0.1 mg/Nm\textsuperscript{3} naphthalene only, Ahrenfeldt et al., 2006

- **Suitable for SOFC operation, 150 hours single cell test completed**
Technology description

APPLICATION OF SYNGAS FROM TWO-STAGE GASIFICATION
TwoStage Gasification | Gas application

1. Cogeneration of **heat and power**

2. Polygeneration of **heat, (power) and biofuels**
Gas application | Flexible CHP
Gas application | CHP production via SOFC

Extremely clean producer gas

Single cell test successful in 2006
(150 h without catalyst degradation)

2 kW stack test starting up 2013

Model results on 500 kW gasifier:
Micro gas turbine (MGT): 28% el / 76% CHP
SOFC: 36% el / 80% CHP
SOFC + MGT: 50% el / 80% CHP
Gas application | Bio-methanol/DME

Thermodynamic model of process:

- 5 MW\textsubscript{TH} input
- Feed stock: Wood chips
- Gas composition as Viking pilot plant
- Once-through => Recycling plant
- Trigeneration of liquid fuel, power and district heating
- Compared to large, centralized plants

Lasse R. Clausen (2011) “Thermodynamic analysis of small-scale DME and methanol plants based on the efficient two-stage gasifier”
Gas application | **BioSNG** (Synthetic Natural Gas)

![Diagram of BioSNG process](image)

- Wood chips are input into a Two-Stage Gasifier.
- The output from the Gasifier is Syngas and Oxygen ($O_2$).
- Syngas enters the Methane reactor to produce Bio-SNG.
- Oxygen is used in the SOEC/SOFC for electricity production.
- Steam is also generated in the SOEC/SOFC.
- Electricity and Heat are produced as byproducts.
Gas application | **BioSNG** (Synthetic Natural Gas)
Gas application | BioSNG (Synthetic Natural Gas)

Plant efficiency estimations by DNA modeling (three designs):

- Biomass-to-SNG efficiency based on LHV: 65-78%
- Overall plant energetic efficiency: 87-90%

From Maria Mita (2013) Production of Synthetic Natural Gas based on the Two-Stage Gasifier. Master Thesis, DTU Mechanical Engineering
BGG | VISION

- Fact: **Biomass is a limited resource!**
- Thus there are three thing that matter:
BGG | VISION

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Thank you for your attention

DTU Chemical Engineering
Department of Chemical and Biochemical Engineering