ECN System for MEthanation (ESME)

G. Aranda Almansa
L.P.L.M. Rabou
C.M. van der Meijden
A. van der Drift

June 2015
ECN-L--15-044
ECN System for MElhanation (ESME)

G. Aranda Almansa, L.P.L.M. Rabou, C.M. van der Meijden, A. van der Drift

Vienna, 4 June 2015
Contents

1. Introduction
2. 500-hour experiment: test conditions
3. 500-hour experiment: results
4. Conclusions
Contents

1. Introduction

2. 500-hour experiment: test conditions

3. 500-hour experiment: results

4. Conclusions
1. Introduction

- ECN: development of technology for efficient production of SNG from biomass gasification → MILENA and OLGA.

- Patented technology for methanation of gas from biomass gasification: ECN System for MEthananation (ESME).

- ESME designed especially for gas from BFB, CFB and allothermal gasifiers (e.g. ECN MILENA, TUV FICFB).
1. Introduction

- ESME concept: smart sequence of the different units:
  - More efficient conversion of producer gas from BG to SNG because HC (e.g. benzene) are not removed but converted → available for conversion to CH$_4$.
  - Prereformer: simultaneous HC reforming and methanation.
  - Reduced compression cost.

- Main parts of the system extensively tested downstream atmospheric gasification.
Contents

1. Introduction
2. 500-hour experiment: test conditions
3. 500-hour experiment: results
4. Conclusions
Experimental layout

MILENA

5 kg/h wood
1 kg/h steam
1 NL/min Ar

To afterburner

Hot gas filter

OLGA

Cooler

Filter

Compressor

Gas meter

5 NmL/min Ne

Gas analysis

ESME system test rig

HDS

R11
H₂S removal

R12
Guard bed

R13
Prereformer

R14
SNG-1

R15
SNG-2

To afterburner

575 g/h steam

Gas analysis

Gas analysis
Experimental layout

- **MILENA**
  - 5 kg/h wood
  - 1 kg/h steam
  - 1 NL/min Ar

- Hot gas filter
- OLGA
- Cooler
- Filter
- Gas meter
- Compressor

- 5 kg/h wood
- 1 kg/h steam
- 1 NL/min Ar

- 575 g/h steam

- Gas analysis
- To afterburner
- Gas meter
- Filter
- ESME system test rig
- HDS
  - R11
  - H₂ S removal
  - R12
  - Guard bed
  - R13
  - Prereformer
  - R14
  - SNG-1
  - R15
  - SNG-2

- Gas analysis
- SNG 1-6
- To afterburner
- SNG-2
Experimental layout

- MILENA
  - 5 kg/h wood
  - 1 kg/h steam
  - 1 NL/min Ar

- OLGA
- Cooler
- Filter
- Compressor
- Gas meter

System test rig
- R13 Prereformer
- R14 SNG-1
- R15 SNG-2

Gas analysis
- SNG 1-4
- SNG 1-5
- SNG 1-6

Gas analysis
- 575 g/h steam
- 4/minute Ne

Gas analysis
- 1 NL/min Ar
Experimental layout

MILENA

Hot gas filter

OLGA

Cooler

Filter

Gas meter

Compressor

5 kg/h wood
1 kg/h steam
1 NL/min Ar

To afterburner

Gas analysis

575 g/h steam

Gas analysis

HDS

R11 H

S removal

R12 Guard bed

R13 Prereformer

R14 SNG

R15 SNG

To afterburner

SNG 1

SNG 1

SNG 1

SNG 1

HDS-5

HDS-4

HDS-3

HDS-2

HDS-1

Gas analysis

SNG 1

Gas analysis
Experimental layout

5 kg/h wood
1 kg/h steam
1 NL/min Ar

Hot gas filter

To afterburner

Filter

Gas meter

5 NmL/min H₂

ESME system test rig

H₂S removal

Guard bed

R11

R12

Gas analysis

11
Experimental layout

MILENA

5 kg/h wood
1 kg/h steam
1 NL/min Ar

OLGA

Cooler

Filter

Compressor

Gas meter

Gas analysis

R13
Prereformer

R14
SNG-1

R15
SNG-2

ESME system test rig

To afterburner

Gas analysis

575 g/h steam

HDS-5

Gas analysis

HDS-5

Gas analysis
Overview 500-hour bio-SNG test

<table>
<thead>
<tr>
<th>Number of operating hours</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>MILENA</td>
<td>OLGA</td>
</tr>
<tr>
<td>580</td>
<td>570</td>
</tr>
</tbody>
</table>

- MILENA: ~90%.
- MILENA + OLGA + ESME ~ 85%.
MILENA operation
HDS unit

- Converts organic S (e.g. thiophene) to \( \text{H}_2\text{S} \) and \( \text{COS} \); hydrogenates \( \text{C}_2\text{H}_4 \) and \( \text{C}_2\text{H}_2 \) into \( \text{C}_2\text{H}_6 \).
- Fixed-bed reactor with commercial CoMoO catalyst.
- Inlet gas T set at 280°C.
- GHSV = 200-250 h\(^{-1}\).
- \( \text{H}_2\text{S} \) and \( \text{COS} \) removed downstream by ZnO.
Prereformer unit, R13

• Converts aromatic HC and produces CH\textsubscript{4} \rightarrow autothermal operation.
• Fixed-bed filled with a commercial Ni-based catalyst (19 mm diameter x 12 mm pellets).
• Operation at ~6 bar; inlet gas T set at 340°C.
• 575 g/h steam added to the gas upstream the reactor.
• GHSV ~ 2000 h\textsuperscript{-1}.
Methanation units, R14 & R15

- Fixed-bed filled with a commercial Ni-based catalyst (4 mm diameter x 5 mm), different from prereformer catalyst.
- R14: inlet gas T set at 230°C.
- R15: inlet gas T set at 240°C.
- GHSV ~ 2000 h⁻¹.
Contents

1. Introduction
2. 500-hour experiment: test conditions
3. 500-hour experiment: results
4. Conclusions
MILENA/OLGA performance

Producer gas composition:

- Trends in time: higher $H_2$ and $CO_2$, lower CO $\rightarrow$ olivine activation over time.
- After shutdown/maintenance (i.e. refilling with fresh bed material): back to initial values.
- OLGA reduces tar content from $\sim 30$ g/Nm$^3$ dry to $\sim 1$ g/Nm$^3$ dry (remaining mainly 1-ring compounds).
ESME performance

Inlet flow rate:

- Target inlet flow: 11 – 12 NL/min.
- Slight variations in flow over time (e.g. adjustment of MILLENA pressure, changing flow resistance over filters, adjustment of compressor frequency).
ESME performance

Pressure drop:

- Pressure drop over ESME (inlet R13 -- outlet R15) ~ 30 mbar throughout the test.
- Similarly to flow, small variations over time.
- Stability of operation of the whole methanation system.
ESME performance

HDS temperature profile:

- Stable operation of HDS reactor.
- Irregular behavior of T4: changes in composition/flow/pressure of inlet gas.
- The HDS catalyst is able to convert organic S compounds down to detection limits.
ESME performance

Prereformer temperature profile:

- T5 decreases over time: catalyst deactivation or variations in pressure or flow over the system.
- Re-start after shutdown resets T5 to initial values.
- After 500 h operation, catalyst degradation not clear from T profile.
- Negligible changes in gas composition over 500 hours.
ESME performance

Methanation-1 & 2 temperature profile:
Evolution of gas composition

- **CH$_4$**: from 11% vol. to ~40% vol.
- **CO**: from 25-28% vol. to ~100 ppmv.
- **H$_2$**: from 26-29% vol. to ~2% vol.
- Thermodynamic equilibrium is reached.
- No apparent change in catalysts activity.
Evolution of gas composition

$C_2H_2, C_2H_4, C_2H_6$:

- $C_2H_4$ and $C_2H_2$ are completely hydrogenated to $C_2H_6$ in the HDS unit.
- Afterwards, $C_2H_6$ is converted in the prereformer.
- Catalytic activity of HDS, prereformer and methanation units remains apparently constant after several hundred hours operation.
Evolution of gas composition

**Benzene, toluene:**

- Benzene: from 5000 ppmv dry (inlet HDS) to approximately 0 ppmv dry after R13.
- Similar trends for toluene.
Contents

1. Introduction
2. 500-hour experiment: test conditions
3. 500-hour experiment: results
4. Conclusions
4. Conclusions

- **ECN System for MEthanation (ESME):** novel technology for SNG from biomass gasification.

- Successful 500-h test downstream MILENA and OLGA in October 2014:
  - MILENA availability ~ 90%; availability of (MILENA + OLGA + ESME) ~ 85%.
  - CH₄ production also in prereformer → positive effect on the heat balance of R13.
  - Catalyst degradation not observed or near detection limits.
  - Catalytic activity of HDS, prereformer and methanation units remains apparently constant after several hundred hours operation.

- **Important step for scale-up of bioSNG production → 300 m³/h SNG pilot-scale facility planned in the Netherlands.**
Lastly...
Thanks for your attention

This work is part of the project Advanced Gas Technology development phase 2 (AGATE2), which has received support from the Energy Delta Gas Research (EDGaR) programme. EDGaR acknowledges the contribution of funding agencies: The Northern Netherlands Provinces (SNN) Investing in your future, the European Fund for Regional Development, the Ministry of Economic Affairs, and the Province of Groningen. Part of the work has been performed within the BRISK Project, which is funded by the European Commission Seventh Framework Programme (Capacities). The work has been co-funded by the Program Subsidy from the Ministry of Economic Affairs.

Contact:
G. Aranda Almansa
aranda@ecn.nl