Overview of achievements in the DEMCAMER project

Ilaria Mirabelli

Workshop: Catalytic membrane reactors, what’s next?
Petten, 29-30 April 2015

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Outlook

• DEMCAMER: project overview

• DEMCAMER Membrane Reactors
  – System layout
  – Pilot scale reactor: specs and description
  – Integration
Design and Manufacturing of Catalytic Membrane Reactors by Developing New Nano-architectured Catalytic and Selective Membrane Materials

over four selected chemical processes:

- Autothermal Reforming (ATR),
- Water Gas Shift (WGS),
- Fischer-Tropsch Synthesis (FTS),
- Oxidative Coupling of Methane (OCM)

Hydrogen production

Liquid hydrocarbons production

Ethylene production

www.demcamer.org
Partnership

17 Partners from 10 different countries:

- 8 Research Centers and Universities
- 4 SMEs
- 5 Large Enterprises
Scientific and Technical Objectives

- New membrane materials and nano-architectured catalysts
- Radical improvements in membrane reactors’
- Validating reactor configurations
- Improving cost efficiency of reactors
- Assessment of the four CMR developed process’
Project Structure

Industrial specifications
- Catalysts development
- Membranes development

Proof of principle
- Lab scale Reactors

Proof of concept
- Pilot scale prototype
- Testing and validation

LCA and risk assessment
Modelling and simulation
Project’s current state

Prototype
Technical designs

Assembly

Pilot test

CMR Modelling & Simulation results
Lab scale Test results
Membranes & catalysts for the pilot scale reactors

3-D design of the Pilot scale reactors
## MR prototypes

<table>
<thead>
<tr>
<th>Chemical processes</th>
<th>Membrane type</th>
<th>Productivity &amp; Conversion targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTS</td>
<td>Membranes for H₂ distribution</td>
<td>CO conversion &gt; 60%</td>
</tr>
<tr>
<td>nCO + (2n+1)H₂ → CₙHₙH₂ + nH₂O</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OCM</td>
<td>Membranes for O₂ distribution</td>
<td>C₂ yield &gt; 30%</td>
</tr>
<tr>
<td>2CH₄ + O₂ → C₂H₄ + 2H₂O</td>
<td>-</td>
<td>CH₄ conversion &gt; 90%</td>
</tr>
<tr>
<td>ATR</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4CH₄ + O₂ + 2H₂O → 4CO + 10H₂</td>
<td>5 Nm³/h H₂</td>
<td>CH₄ conversion &gt; 90%</td>
</tr>
<tr>
<td>WGS</td>
<td>Membranes for H₂ extraction</td>
<td>5 Nm³/h H₂</td>
</tr>
<tr>
<td>CO + H₂O ↔ CO₂ + H₂</td>
<td>-</td>
<td>CO conversion &gt; 95%</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>H₂ recovery &gt; 90%</td>
</tr>
</tbody>
</table>
WGS-MR System layout

Reformate

Hydrogen output

Steam as sweep gas

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## Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
<th>Feed comp.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen output</td>
<td>Nm³/h</td>
<td>5</td>
<td>CH₄</td>
<td>3.8</td>
</tr>
<tr>
<td>Hydrogen recovery factor [HRF]*</td>
<td>%</td>
<td>90</td>
<td>H₂</td>
<td>44.8</td>
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<tr>
<td>CO conversion</td>
<td>%</td>
<td>95</td>
<td>CO</td>
<td>9.2</td>
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<tr>
<td>Hydrogen purity</td>
<td>%</td>
<td>99.9</td>
<td>CO₂</td>
<td>4.7</td>
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<tr>
<td>Feed pressure</td>
<td>bar</td>
<td>6</td>
<td>H₂O</td>
<td>34.7</td>
</tr>
<tr>
<td>Inlet temperature</td>
<td>°C</td>
<td>&gt; 300</td>
<td>N₂</td>
<td>2.8</td>
</tr>
</tbody>
</table>

\[
HRF = \frac{F_{H₂ permeate}}{F_{H₂ feed} + F_{CO feed}}
\]
• **Packed bed 1D model:**

CO conversion and $H_2$ Recovery as a function of feed temperature. Sweep factor 0.06, membrane area 0.152 m².

$H_2$ Recovery as a function of sweep factor for different membrane area. Feed temperature 330°C.
WGS-MR
Reactor simulation & design

Design:
- Packed bed reactor
- Tubes in tube configuration
- Sweep flow (steam), 1.0 kg/h counter current
- < 0.2 m² membrane area
WGS-MR Integration

Catalyst technology:
• HYBRID CATALYSIS

Membrane technology:
• RAUSCHERT, supports
• TECNALIA, membrane deposition
• TECNALIA / TUE, sealing

Feed

Sweep

H₂ + Sweep

Retentate

Membrane tube

Catalytic packed bed
WGS-MR Assembly

Assembly cabinet designed as for the HyGear Onsite Hydrogen Generation Systems (Hy.GEN)

✓ Compact
✓ Suitable for outdoors
✓ Easily transportable

1. Ventilation Fans
2. Reformer Unit
3. DI Water Storage
4. Electronics Cabinet
5. Desulfurization Vessel
6. Steam Generator
7. Water Pumps
8. Water Gas Separator
9. Water Purification System
10. Ice Exchanger
11. Coolant Expansion Vessel
12. Burner Air Blower
13. PSA Vessels
14. Off-gas Storage
15. H2 Storage
16. Reforming Cooler
WGS-MR Assembly

Assembly cabinet: front view

Assembly cabinet: back view

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WGS-MR Prototypes Testing and Validation

Testing of the WGS pilot scale prototype includes:

- Duration test
- Thermal cycling tests (e.g., varying feed and sweep stream temperatures)
- Variations of production rates (e.g., feed flow rate)
- Variations of feed gas compositions.

Comparison with industrial requirements and specifications
- CO conversion target > 95%
- H₂ recovery target > 90%

MRs Modelling & Simulation
- Pilot scale model validation
- Model improvement

LCA and the accidental industrial risk assessment

Test plan results
"Catalytic Membrane reactors, what's next?"

Aspects to look at[^1]:

- Re-design and optimization of the whole MR integrated process
- Successful pilot demonstration of the membrane technology in a “realistic” operation environment
- Economic outlooks

Membrane Manufacturing:
- Scale-up challenges
- Raw material: cost, availability, possible material recycling

[^1] Joint Workshop on: *Scale-up of Pd Membrane Technology: From Fundamental Understanding to Pilot Demonstration*  
Thank you for your attention

HyGear
www.hygear.nl
contact: ilaria.mirabelli@hygear.nl

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29-04-2015 / Page 18

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