DRYREF™ & SYNSPIRE™
Innovation for HyCO applications

Thomas Bartesch
Austin, October 29th 2019

Making our world more productive
1. BASF & LINDE: Innovation through partnership
2. Process Introduction
3. Case Evaluation
4. CO₂ Footprint
5. Summary
BASF & LINDE: Innovation through partnership
SYNSPIRE™ G1-110 and DRYREF™

- BASF SYNSPIRE™ G1-110 catalyst developed to improve syngas generation by steam reforming
- Challenge: Reduction of process steam without coke-formation on catalyst
- Use of CO₂ as additional feedstock

Catalyst available for new plants and revamp together with Linde’s DRYREF™ technology

Partnership with acknowledged R&D institute and universities

SYNSPIRE™ G1-110
Unique catalyst for DRYREF™ by BASF

First commercial reference
Linde HyCO unit 08/2017-07/2018
Full product utilization
Process Introduction
Simplified process arrangement

- Simplified typical process arrangement based on natural gas as feedstock and Steam Methane Reforming (SMR)
- Pre-reformer as optional equipment
- H₂/CO product ratio as target
- Direct use of syngas up- or downstream of CO₂ removal is also possible
Process Introduction
CO₂ recycle and CO₂ import

How to adjust H₂/CO ratio in syngas?
- CO₂ recycle for reduction of H₂/CO ratio
- CO₂ import for full flexibility of H₂/CO product ratio
- DRYREF process is typically used for natural gas based H₂ + CO plants
- DRYREF catalyst allows lower S/C ratio which improves OPEX and energy efficiency
- No pre-reformer required (depending on NG quality)
- CO₂ recycle to SMR with optional additional CO₂ import
## Case Evaluation
### Scenario 1 – without CO₂ import

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Steam to Process: S/C</th>
<th>CO₂ Recycling</th>
<th>Additional Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional process</td>
<td>2.5 mol/mol</td>
<td>Full CO₂</td>
<td>No additional</td>
</tr>
<tr>
<td>Conventional process incl. Pre-Reformer</td>
<td>2.0 mol/mol</td>
<td>Full CO₂</td>
<td>Pre-Reformer</td>
</tr>
<tr>
<td>DRYREF process</td>
<td>1.5 mol/mol</td>
<td>Full CO₂</td>
<td>BASF catalyst</td>
</tr>
</tbody>
</table>

- BASF catalyst (SYNSPIRE™ G1-110)
- No additional equipment

Conditions are resulting in H₂/CO product ratio of 2.45 mol/mol

### Specific Energy Consumption

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Specific Energy Consumption [GJ/1000Nm³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>13.50</td>
</tr>
<tr>
<td>Conventional incl. Pre-Reformer</td>
<td>13.32</td>
</tr>
<tr>
<td>DRYREF</td>
<td>13.15</td>
</tr>
</tbody>
</table>

- Conventional: 100 %
- Conventional incl. Pre-Reformer: 98.7 %
- DRYREF: 97.4 %

- Specific energy consumption as \((\text{Feed} + \text{Fuel - Steam}) / (H_2 + CO)\) [GJ/1000Nm³]
Case Evaluation
Scenario 1 – without CO₂ import

**OPEX comparison on basis of:**
- NG-feed & fuel: 13 $/MMBTU
- Electricity: 99 $/MWh
- Steam: 33 $/t

**Example:** 50000 Nm³/h H₂+CO plant
- Resulting in OPEX savings of 12 Mio$ in 5 years compared to conventional process

**CAPEX comparison:**

<table>
<thead>
<tr>
<th></th>
<th>Convent.</th>
<th>Pre-Ref</th>
<th>DRYREF</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPEX</td>
<td>100%</td>
<td>98.2%</td>
<td>97.4%</td>
</tr>
</tbody>
</table>

Basis: EPC, western Europe
Case Evaluation
Scenario 2 – including CO₂ import

**Conventional process**
- Steam to process: S/C 2.5 mol/mol
- Full CO₂ recycle + CO₂ import
- No additional equipment

**Conventional process incl. Pre-Reformer**
- Steam to process: S/C 2.0 mol/mol
- Full CO₂ recycle + CO₂ import
- Additional equipment: Pre-Reformer

**DRYREF process**
- Steam to process: S/C 1.5 mol/mol
- Full CO₂ recycle + CO₂ import
- BASF catalyst (SYNSPIRE™ G1-110)
- No additional equipment

**H₂/CO product ratio of 1.5 mol/mol adjusted by CO₂ Import**

Specific energy consumption as 
(Feed + Fuel - Steam) / (H₂+CO) [GJ/1000Nm³]

- Conventional: 100% (14.20)
- Conventional incl. Pre-Reformer: 97.9% (13.9)
- DRYREF: 95.4% (13.55)
Case Evaluation
Scenario 2 – including CO₂ import

OPEX comparison on basis of:
- NG-feed & fuel: 13 $/MMBTU
- Electricity: 99 $/MWh
- Steam: 33 $/t

Example: 50000 Nm³/h H₂+CO plant
- Resulting in OPEX savings of 20 Mio$ in 5 years compared to conventional process

CAPEX comparison:

<table>
<thead>
<tr>
<th></th>
<th>Convent.</th>
<th>Pre-Ref</th>
<th>DRYREF</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPEX</td>
<td>100%</td>
<td>98.8%</td>
<td>97.3%</td>
</tr>
</tbody>
</table>

Basis: EPC, western Europe
Case Evaluation
Scenario 2 – including CO₂ import

OPEX comparison on basis of:
- NG-feed & fuel: 13 $/MMBTU
- Electricity: 99 $/MWh
- Steam: 20 $/t

**Example:** 50000 Nm³/h H₂+CO plant
- Resulting in OPEX savings of 20 Mio$ in 5 years compared to conventional process

Design for minimized steam production

**OPEX reduction:** ~5 %
(diagram values rounded)
Case Evaluation
Scenario 2 – including CO₂ import

OPEX comparison on basis of:
- NG-feed & fuel: 5 $/MMBTU
- Electricity: 50 $/MWh
- Steam: 12 $/t

Example: 50000 Nm³/h H₂+CO plant
- Resulting in OPEX savings of 8 Mio$ in 5 years compared to conventional process

OPEX reduction: ~5 %
(diagram values rounded)
CO₂ Footprint
DRYREF as CO₂ consuming process

- CO₂ Import is used to compensate direct CO₂ emissions from reformer flue gas
- Plant design for high air preheat temperature and minimum steam production
- Break-even to negative CO₂ emissions for DRYREF at H₂/CO product ratio of 1.5 (molar basis)
Summary

DRYREF Process

- DRYREF process is typically used for natural gas based H₂+CO plants
- BASF catalyst (SYNSPIRE™ G1-110) offers possibility for operation at low S/C ratio without pre-reforming
- Energy Efficiency and OPEX is highly beneficial compared to conventional process arrangements
- CAPEX is highly competitive for new built plants
- CO₂ footprint is beneficial compared to conventional process
- CO₂ footprint is getting negative at H₂/CO product ratios below 1.5 mol/mol and minimum steam production

Outlook

- Each project is different. Linde will provide optimized tailor made solution for your individual scenario.
- Further field of DRYREF application: Revamp projects or direct refill (customized scenarios)

→ contact Linde Engineering for checking DRYREF feasibility for your project
Thank you for your attention.

Linde Engineering
Thomas Bartersch
Tel +49 89 7445-3498
thomas.bartersch@linde.com

Making our world more productive