Natural Gas Liquefaction Technology for Floating LNG Facilities

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FLNG Facility

What liquefaction process to select for FLNG?
Process Evaluation

• Process efficiency
  \[
  \frac{\text{LNG production}}{\text{Refrigeration power}}
  \]
  - Strong impact on plant efficiency
    \[
    \frac{\text{LNG production}}{\text{NG feed rate}}
    \]

• Train capacity

• Equipment count
Challenges for Floating LNG

- Weight, size and layout limits
  - Impact of process capacity and equipment count
- Wave and wind induced vessel motions
  - Mechanical strength requirements
  - Effect on two-phase flow
- Flammable inventory
  - Propane may attract concern
- Corrosive marine environment

Solutions

- Robust equipment design
- Appropriate selection of process cycle
Coil Wound Exchangers for Safety and Reliability

- Liquefying hydrocarbons can cause high thermal stresses
  - CWHE proven to resist these stresses
- Dual containment (tubes inside shell)
- Tubes resistant to blockages
- Stable operation at significant turndown
- Small footprint
- High availability = higher revenues
Challenges for Floating LNG

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  – Impact of process capacity and equipment count
• Wave and wind induced vessel motions
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  – Effect on two-phase flow
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• Corrosive marine environment

Solutions

• Robust equipment design
• Appropriate selection of process cycle
Process Cycle Scorecard

- Process efficiency/capacity
- Equipment count
- Flammable refrigerant, C3 inventory
- Motion sensitivity (Two-phase refrigerant)

<table>
<thead>
<tr>
<th>Process</th>
<th>Relative Efficiency</th>
<th>Train Capacity MTPA</th>
<th>Equipment Count</th>
<th>Flammable Refrigerant</th>
<th>Significant C3 Inventory</th>
<th>Motion Sensitivity</th>
</tr>
</thead>
</table>
Liquefaction Processes

Mixed Refrigerant

N₂ Recycle

Single Refrigerant

Pre-cooled
Pre-cooled Mixed Refrigerant

• C3MR process – propane precooling
  – Highest efficiency, large capacity – 5+ MTPA
  – Propane inventory, footprint

• DMR – use 2\textsuperscript{nd} MR for precooling
  – Same efficiency and capacity
  – Propane inventory can be minimized

• Motion sensitivity of two-phase flow?
Coil Wound Exchangers with FLNG Vessel Motion

- Thorough mechanical analysis and testing
- Process effects of motion on two-phase flow are mitigated by proper design
  - Detailed design verification program
  - Lab-scale and pilot-scale experiment
  - Analysis including CFD and dynamic hydraulic modeling
  - Suite of exchanger design tools for FLNG
- Independent internal and external reviews
Pre-cooled Mixed Refrigerant

- C3MR process – propane precooling
  - High efficiency, large capacity – 5+ MTPA
  - Propane inventory, footprint
- DMR – use 2\textsuperscript{nd} MR for precooling
  - Same efficiency and capacity
  - Propane inventory can be minimized
- Motion sensitivity of two-phase flow
  - Mitigated with proper CWHE design
Liquefaction Processes

Mixed Refrigerant

$\text{N}_2$ Recycle

Single Refrigerant

Pre-cooled
Single Mixed Refrigerant

- Reduced equipment count
- 1-2 MTPA capacity for single train
- ~ 87% of C3MR/DMR process efficiency
- Like DMR, propane can be minimized
- Motion sensitivity of two-phase flow
  - Mitigated with proper CWHE design
Liquefaction Processes

Mixed Refrigerant

N₂ Recycle

Single Refrigerant

Pre-cooled
$N_2$ Recycle Process

- $N_2$ expansion process for refrigeration
  - Multiple turboexpanders
- No HC refrigerant
- All vapor refrigerant
  - No motion sensitivity
  - Higher flow rates and larger piping
- ~ 1.5 MTPA single train capacity
- ~ 75% of C3MR/DMR process efficiency
Liquefaction Processes

Mixed Refrigerant

N₂ Recycle

Single Refrigerant

Pre-cooled
Precooled $\text{N}_2$ Recycle

- No HC refrigerant
  - CO2, HFC, or LiBr precooling
- Motion sensitivity only for precoolers
  - Mitigate with proper design
- ~ 2 MTPA single train capacity
- ~ 85% of C3MR/DMR process efficiency
# Process Cycle Scorecard

<table>
<thead>
<tr>
<th>Process</th>
<th>Relative Efficiency</th>
<th>Train Capacity MTPA</th>
<th>Equipment Count</th>
<th>Flammable Refrigerant</th>
<th>Significant C3 Inventory</th>
<th>Motion Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3MR</td>
<td>100</td>
<td>5+</td>
<td>Typical</td>
<td>Yes</td>
<td>Yes</td>
<td>Mitigated</td>
</tr>
<tr>
<td>DMR</td>
<td>100</td>
<td>5+</td>
<td>Typical</td>
<td>Yes</td>
<td>No</td>
<td>Mitigated</td>
</tr>
<tr>
<td>SMR</td>
<td>87</td>
<td>1-2</td>
<td>Lower</td>
<td>Yes</td>
<td>No</td>
<td>Mitigated</td>
</tr>
<tr>
<td>Precooled N₂</td>
<td>85</td>
<td>~2</td>
<td>Higher</td>
<td>No</td>
<td>No</td>
<td>Mitigated</td>
</tr>
<tr>
<td>N₂ Recycle</td>
<td>75</td>
<td>~1.5</td>
<td>Higher</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Summary

• A variety of process cycles are suitable for FLNG
  – DMR: High efficiency, high capacity, low C3 inventory
  – SMR: Simple and compact, low C3 inventory
  – N₂ Recycle: No flammable refrigerants, insensitive to vessel motion
  – Precooled N₂ Recycle: Improved efficiency and capacity, no HC refrigerants

• CWHE provides robust design for FLNG
  – Able to resist thermal stresses in liquefaction service
  – Small footprint
  – Motion effects on process/equipment are mitigated
  – Air Products is the process licensor and CWHE supplier for the two FLNG facilities now in EPC phase
There are many suitable processes for FLNG – Select the best one for you.
Thank you