Designing Flexible Plants for Market Adaptation

Jonathan Berg
Lead Process Engineer
Air Products and Chemicals, Inc.

Co-authors:
William Schmidt,
Dr. CHEN Fei, Christopher Ott
Discussion Topics

- Feed Gas Flexibility
  - HHC Removal
  - Nitrogen Removal
  - Helium Recovery

- Liquefaction Process Flexibility
  - Refrigerant Type and Process
  - Optimal Train Capacity (# trains)
  - Parallel Equipment
  - Turndown Considerations

Feed → AGRU, Driers, Hg Removal → NGL & HHC Removal → Liquefaction → MCHE → Storage

See Paper
Pipeline Feed Gas Variability

![Graph showing methane and C6+ concentration over time](image-url)
Feed Gas Composition Effects on Vapor-Liquid Separation
HHC Removal Techniques – Relative Flexibility

- TSA + Partial Condensation
- TSA
- Partial Condensation
- Integrated Scrub Column
- NGL Extraction

Feed Gas Composition

Lean → Rich
Discussion Topics

• Feed Gas Flexibility
  – HHC Removal
  – Nitrogen Removal
  – Helium Recovery

• Liquefaction Process Flexibility
  – Refrigerant Type and Process
  – Optimal Train Capacity (# trains)
  – Parallel Equipment
  – Turndown Considerations
Liquefaction Processes – Basic Components

Liquefaction Train

- Refrigerant Compressors
- Piping
- Heat Exchangers
Single vs Parallel Equipment

Note: For equal pressure drops, pipe sizes shown are to scale
Pressure drop through a pipe can be defined as:

$$\Delta P = \left( f \frac{L}{D_i} \right) \frac{\rho}{2} \nu^2$$

Since: 

$$v = \frac{m}{\rho A} = \frac{m*4}{\rho \pi D_i^2}$$

$$f = \frac{0.316}{Re^{0.25}} = \frac{0.316}{\left( \frac{\rho v D_i}{\mu} \right)^{0.25}}$$

\[
\Delta P = C_1 \left( \frac{m_{1.75}^{1.75}}{D_i^{4.75}} \right) = C_1 \left( \frac{m}{D_i} \right)^{0.368}
\]

For equal pressure drops:

$$\Delta P_1 = \Delta P_2 = C_1 \left( \frac{m_{1.75}^{1.75}}{D_i^{4.75}} \right) = C_1 \left( \frac{m_{2.75}^{1.75}}{D_i^{4.75}} \right) \text{ so } \frac{D_{i2}}{D_{i1}} = \left( \frac{m_2}{m_1} \right)^{1.75/4.75} = \left( \frac{m_2}{m_1} \right)^{0.368}$$

To calculate volume of pipe metal required for $N$ parallel pipes:

**required pipe thickness, $t$, is $\sim D_i$ so metal volume, $V = \pi (D_i + t) * t$**

if, $V \sim D_i^2$, then

$$V_2 \frac{V_1}{V_1} = \left( \frac{D_{i2}}{D_{i1}} \right)^2 = \left( \frac{m_2}{m_1} \right)^{1.75/4.75} \left( \frac{m_2}{m_1} \right)^{0.737} \text{ Scale-up factor}$$
Single vs Parallel Equipment

- (1 pipe x 100% flow) vs (2 pipes x 50% flow)

\[ V_{metal,2} = V_{metal,1} \times \left( \frac{m_2}{m_1} \right)^{0.737} = 100\% \times \left( \frac{50\%}{100\%} \right)^{0.737} = 60\% \]

\[ 2 \times V_{metal,2} = 2 \times 60\% = 120\% \]

<table>
<thead>
<tr>
<th>( N ) pipes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative metal volume, %</td>
<td>100%</td>
<td>120%</td>
<td>134%</td>
<td>144%</td>
<td>153%</td>
<td>183%</td>
<td>204%</td>
<td>220%</td>
<td>245%</td>
</tr>
</tbody>
</table>

- Due to inherent modular design characteristics, cost scale-up factors for some major equipment (e.g. CWHE’s) often range from 0.4 to 0.8
Case Study C: Optimal Number of Liquefaction Trains

• Assumptions:
  – Linear demand growth of 1 mtpa per year from years 1 thru 6 (5 mtpa total)
  – $1,000 / tpa CAPEX for a single 5 mtpa train (MM$5,000 total)
  – 48 month installation time for 5 mtpa train; schedule scale-up factor of 0.4
  – Discount rate: 12%
  – Inflation rate: 2%
  – Revenue based on $7/MMBtu

• Example - 3 trains with 0.8 CAPEX scale-up factor
  – Capacity per train: 5.0/3 = 1.67 mtpa
  – CAPEX required per train: 5,000*(1.67/5.0)^{0.8} = MM$2,076
  – Total CAPEX = 3*MM$2,076 = MM$6,229
  – Required installation time per train: 48*(1.67/5.0)^{0.4} = 31 months
    • Installation interval of 12 months
Case Study C: Schedule and NPV Analysis

Discounted Payback Period of 9.5 years
Case Study C: Discounted Payback Periods

1 train has fastest payback period for scale-up factors less than ~0.8
Case Study C: Conclusion

- The conditions necessary for many smaller liquefaction trains to offer an overall economic benefit are:
  - No economies of scale
  - Expedited product demand met with fast onstream times
  - Ramped product demand curve closely matched with staged investments
  - Relatively high discount rate and LNG price

- Other influencing factors
  - Technology limitations
  - Project financing
### Single vs Parallel Equipment – Operating Impacts

Assume 95% availability for each unit

<table>
<thead>
<tr>
<th>$N$ parallel units</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total trips per year (assuming 6/unit/year)</td>
<td>6</td>
<td>12</td>
<td>18</td>
<td>24</td>
<td>30</td>
<td>60</td>
<td>90</td>
<td>120</td>
<td>180</td>
</tr>
</tbody>
</table>
Turndown

- Consider turndown capability of installed equipment
- **Efficient** turndown typically can be achieved down to:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Minimum Flow (% of Design)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressors</td>
<td>60-80%</td>
</tr>
<tr>
<td>Flash Drums</td>
<td>0%</td>
</tr>
<tr>
<td>Distillation Columns</td>
<td>20-80%</td>
</tr>
<tr>
<td>Heat exchangers</td>
<td>0%</td>
</tr>
<tr>
<td>Adsorption Units</td>
<td>0%</td>
</tr>
<tr>
<td>CWHE’s</td>
<td>~5%</td>
</tr>
</tbody>
</table>

- Distillation columns no longer separate, so no turndown below 20-80%
- Compressors recycle below 60-80%, so only lose efficiency
Parallel Compression Benefits

- Parallel compression can:
  - Extend efficient turndown range
  - Debottleneck compressor aerodynamics
  - Increase probability of at least 1 string operating
    - Keeps cryogenic equipment cold and operating
    - Decreases number of warm-ups and cooldowns (and possibly flaring)

- Advancing compressor driver arrangements enable:
  - More use of parallel compression strings
  - Shifting power between precooling and liquefaction compressors
Conclusions

- Feed gas variability affects the HHC removal technology selection
- Fundamental economies of scale impact optimal number of trains
- Parallel units can improve availability but increase number of trips / startups
- Synergies exist for parallel compression within a common liquefaction train

*More is not always better. Bigger can be better. And one size certainly does not fit all.*