Exchanger Selection & Design in an LPG Recovery Unit

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• Petrofac is the largest UK-listed service provider to the international oil & gas industry (FTSE #60), with more than 15,000 employees across the world

• We have 30 years’ experience and a track record of several hundred projects across our key markets of the Middle East, Africa, CIS, Asia Pacific and UK Continental Shelf

• Our capabilities span the oil & gas value chain; subsurface, asset management, field development, engineering, construction, operations, maintenance and training

• We provide these services as standalone offerings but increasingly we offer our capabilities as integrated services to resource holders to enable them to develop their assets – we call this business “Integrated Energy Services” (IES)

• Whilst IES may deploy capital, we are fundamentally a service company, not an oil company – we don’t do exploration and we don’t seek to book reserves

• We have been ranked number one EPC contractor in 2010 and 2011 in Oil & Gas Middle East and annually train more than 50,000 delegates
Outline

• Background
  o Where does LPG recovery fit into the overall oil & gas process
  o Introduce typical turbo-expander based recovery processes

• Case Study
  o Impact of approach temperatures on recovery and exchanger design
  o Advantages of plate fin exchangers
  o Design in Aspen HYSYS® using HTFS modules (Aspen Shell& Tube and Aspen Plate Fin Exchanger program)
  o Design considerations for plate fin exchangers
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Processes

- Lean Oil Absorption
- External Refrigeration
- Expansion Refrigeration Joule Thompson Cooling
  - J-T Valve
  - Turbo Expander

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Conventional Expander process

- **INLET GAS**
- **RESIDUE GAS**
- **Heat Exchangers**
- **Reciprocator**
- **Turbo Expander**
- **Low Temperature Separator**
- **Deethaniser**
- **C3+ PRODUCT**
Refluxed Deethaniser Process
Overhead Recycle (OHR) Process

INLET GAS

RESIDUE GAS

Recompressor

Condenser

Heat Exchangers

Low Temperature Separator

Turbo Expander

Absorber

Deethaniser

C3+ PRODUCT

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Case Study: LPG Recovery

Feed gas
Inlet Pressure 74 barg

<table>
<thead>
<tr>
<th>Design Case</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate, MMSCFD</td>
<td>500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Composition</th>
<th>% mol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>1</td>
</tr>
<tr>
<td>CO₂</td>
<td>1.5</td>
</tr>
<tr>
<td>Methane</td>
<td>75</td>
</tr>
<tr>
<td>Ethane</td>
<td>16</td>
</tr>
<tr>
<td>Propane</td>
<td>4</td>
</tr>
<tr>
<td>i-Butane</td>
<td>0.5</td>
</tr>
<tr>
<td>n-Butane</td>
<td>1.5</td>
</tr>
<tr>
<td>i-Pentane</td>
<td>0.5</td>
</tr>
<tr>
<td>n-Pentane</td>
<td>0</td>
</tr>
</tbody>
</table>

Gas to Reinjection
340 barg pressure

LPG min 90% recovery
C₂ and lighter <2.6% mol
Iso & N Pentane <0.4% mol

LPG recovery critical to plant economics since gas is used for reinjection, revenue is only from LPG recovered.
Case Study: Process Selection

- Process schemes considered

1. Expander scheme with a refluxed de-ethaniser
2. Overhead recycle (OHR) process

- The OHR process gave higher LPG recoveries of more than 10% for similar operating conditions

- In the subsequent discussion impact of temperature approach and exchanger selection on LPG recovery for OHR process is examined
OHR process

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Cooling scheme: Shell & Tube 10 Deg C approach
Cooling scheme: Shell & Tube 5 Deg C approach

- Exchanger E-1 deleted since duty becomes very low due to better approach in E-3
- Increase in Turbo-expander inlet pressure corresponding to E-1 pressure drop
Cooling scheme: Plate-fin exchanger

- Exchangers E-2 & E-3 replaced by single LNG exchanger
- Control valves in feed line deleted since no splitting of feed required
- Higher Turbo expander inlet pressure due to control valve deletion
Effect of Exchanger Approach Temperature on LPG Recovery

![Graph showing the effect of exchanger approach temperature on LPG recovery](diagram)

- **LPG Recovery %**
- **T-E Power MW**

**Exchanger Approach Temperature Deg C**

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Exchanger Sizing: Shell & Tube

<table>
<thead>
<tr>
<th>Case</th>
<th>10 deg C app</th>
<th>5 deg C app</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exchanger</td>
<td>aE1</td>
<td>E2</td>
</tr>
<tr>
<td>Heat exchanged, kW</td>
<td>1418</td>
<td>2157</td>
</tr>
<tr>
<td>Configuration</td>
<td>1P, 1S</td>
<td>1P, 2S</td>
</tr>
<tr>
<td>Surface area, m²</td>
<td>238</td>
<td>223</td>
</tr>
<tr>
<td>Geometry</td>
<td>BEM</td>
<td>BEU</td>
</tr>
<tr>
<td>Total cost, $ (HTFS)</td>
<td>2.8 million</td>
<td></td>
</tr>
</tbody>
</table>

Closer approach temperatures result in

- More complex exchanger designs
- Greater degree of uncertainty in the design
Features of Plate-fin exchangers

LNG Exchangers/ Brazed Aluminum exchangers/ Plate-fin exchangers

- Simple construction, compact and lightweight design
- Can handle more than 2 streams
- Useful for low temperature applications
- Can handle phase change
- Can handle close temperature approach that becomes very difficult with shell & tube exchangers
- Not prone to vibration problems as in Shell & tube exchangers in Gas-Gas service
Plate-fin Exchanger : Construction

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## Plate-fin Summary

### Overall Summary

<table>
<thead>
<tr>
<th>Calculation mode</th>
<th>Stream by stream simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exchanger type</td>
<td>Standard axial flow</td>
</tr>
<tr>
<td>Overall heat transfer calculated</td>
<td>kW</td>
</tr>
<tr>
<td>Overall surface area ratio</td>
<td></td>
</tr>
<tr>
<td>Mean temperature difference</td>
<td>°C</td>
</tr>
<tr>
<td>UA value of calculated duty</td>
<td>kW/K</td>
</tr>
<tr>
<td>Core length</td>
<td>mm</td>
</tr>
<tr>
<td>Core width</td>
<td>mm</td>
</tr>
<tr>
<td>Number of layers per exchanger</td>
<td></td>
</tr>
<tr>
<td>Number of exchangers in parallel</td>
<td></td>
</tr>
</tbody>
</table>

### Main stream number

<table>
<thead>
<tr>
<th>Stream</th>
<th>Stream 1</th>
<th>Stream 2</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Cold</td>
<td>Hot</td>
<td>Cold</td>
</tr>
<tr>
<td>Flow direction</td>
<td>End B to A (up)</td>
<td>End A to B (down)</td>
<td>End B to A (up)</td>
</tr>
<tr>
<td>Number of layers (total)</td>
<td>54</td>
<td>34</td>
<td>13</td>
</tr>
<tr>
<td>Total mass flow rate</td>
<td>kg/s</td>
<td>124.3531</td>
<td>146.3246</td>
</tr>
<tr>
<td>Heat load</td>
<td>kW</td>
<td>24534.6</td>
<td>-33725.4</td>
</tr>
<tr>
<td>Percent of specified heat load</td>
<td></td>
<td>102.26</td>
<td>102.49</td>
</tr>
<tr>
<td>Area ratio</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

### Inlet conditions

<table>
<thead>
<tr>
<th>Temperature</th>
<th>°C</th>
<th>Inlet temperature</th>
<th>Outlet temperature</th>
<th>Outlet temperature as input</th>
<th>Inlet pressure</th>
<th>Outlet pressure</th>
<th>Pressure drop (friction)</th>
<th>Percent of allowed pressure drop</th>
<th>Allowed pressure drop</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-36.82</td>
<td>-15.87</td>
<td>54.84</td>
<td>13.15</td>
<td>63.6633</td>
<td>0.9695</td>
<td>0.10953</td>
<td>1</td>
</tr>
</tbody>
</table>

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Plate-fin Exchanger Temperature Profile
Plate-fin Exchanger Diagram

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Comparison of configurations

6 Shell & Tube Exchangers

Single Plate-fin

Replaced by
## Comparison

<table>
<thead>
<tr>
<th></th>
<th>5 deg C approach</th>
<th>3 deg C approach</th>
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</thead>
<tbody>
<tr>
<td>Exchanger type</td>
<td>S&amp;T exchanger</td>
<td>Plate fin exchanger</td>
</tr>
<tr>
<td>LPG recovered</td>
<td>TPH</td>
<td>68.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>69.85</td>
</tr>
<tr>
<td>Additional revenue @ $400 / ton LPG</td>
<td>Million $ /annum</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.5</td>
</tr>
<tr>
<td>Exchanger volume</td>
<td>m3</td>
<td>284</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>Exchanger weight (empty)</td>
<td>MT</td>
<td>564</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Exchanger weight (with water)</td>
<td>MT</td>
<td>812</td>
</tr>
<tr>
<td></td>
<td></td>
<td>130</td>
</tr>
<tr>
<td>Exchanger cost</td>
<td>Million $</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Expected to be less (1/2 to 1/3)</td>
</tr>
</tbody>
</table>
Critical Design Factors for Plate fin exchangers

- Presence of Mercury in gas
  - Mercury and Aluminum form amalgam, loss of integrity due to Liquid Metal Embrittlement (LME)
  - Mercury condenses in the exchangers and can cause reduced performance
  - Recommend installation of upstream Mercury Removal Unit (MRU)
  - Mercury tolerant designs being offered by manufacturers

- Conformance to standards
  - ALPEMA (Brazed Aluminum Plate-Fin Heat Exchanger Manufacturers’ Association)
Critical Design Factors for Plate fin exchangers

- **Plugging**
  - Small particles can plug the small clearances in the exchangers
  - Filters provided upstream (80 Tyler mesh)

- **Thermal Stress**
  - Controlled startup/shutdown to avoid thermal stress
  - Limit temperature difference between adjacent streams during cool down/warm up/dryout operations
  - Avoid liquid being totally vapourised - can lead to flow instabilities due to dryout

- **Operation familiarity**
  - Need to provide training, services and build operator confidence
Conclusion

- LPG recovery operations require efficient heat (cold) recovery to maximize product recovery

- Conventional S&T exchangers difficult to design due to problems of
  - Temperature cross due to close approach temperatures
  - Possible vibration in gas-gas exchangers

- Plate fin exchangers fill this need
  - Simulations help in initial design of plate fin exchanger configurations which will be further refined with vendor input
  - Process with plate-fin exchangers could bring about $5.5M/year additional revenue in addition to capital cost savings due to smaller exchanger footprint
  - Proper installation and care need to be taken to realise potential of plate fin exchangers