Optimal operation of a mixed fluid cascade LNG process

Jørgen Bauck Jensen & Sigurd Skogestad
Department of Chemical Engineering, NTNU Trondheim Norway

Introduction

Large amounts of natural gas (NG) are found at locations that makes it infeasible or not economical to transport it in gaseous state (in pipelines or as compressed NG) to the customers. The most economic way of transporting NG over long distances is to first produce liquefied natural gas (LNG) and then transport the LNG by ships. At atmospheric pressure LNG has approximately 600 times the density of gaseous NG and a temperature of approximately $-162^\circ$C. The process of cooling and condensing the NG requires large amounts of energy.

Process description

Optimization results for the four cycles

<table>
<thead>
<tr>
<th>Cycles</th>
<th>PC1</th>
<th>PC2</th>
<th>LC</th>
<th>SC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_l$ [bar]</td>
<td>6.45</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>$P_m$ [bar]</td>
<td>6.45</td>
<td>6.45</td>
<td>-</td>
<td>28.38</td>
</tr>
<tr>
<td>$P_h$ [bar]</td>
<td>15.03</td>
<td>15.03</td>
<td>20.58</td>
<td>56.99</td>
</tr>
<tr>
<td>$n$ [mol s$^{-1}$]</td>
<td>464</td>
<td>685</td>
<td>390</td>
<td>627</td>
</tr>
<tr>
<td>$W_c$ [MW]</td>
<td>1.2565</td>
<td>2.644</td>
<td>2.128</td>
<td>3.780+1.086</td>
</tr>
</tbody>
</table>

Optimal composition of refrigerant

- Methane [%] 0.00 0.00 4.02 52.99
- Ethane [%] 37.70 37.70 82.96 42.45
- Propane [%] 62.30 62.30 13.02 0.00
- Nitrogen [%] 0.00 0.00 0.00 4.55

- The total shaft work is 10.9 MW
- Optimally the temperatures at heat exchanger outlets are:
  - PCHX1: $-17.3^\circ$C
  - PCHX2: $-51.5^\circ$C
  - LCHX: $-77.1^\circ$C

Temperature profiles

Implementation

1. Feed and composition of refrigerants assumed given
2. Control 12 active constraints:
   - Super-heating before 4 compressors
   - LNG outlet temperature
   - Low pressure in all cycles
   - Maximum cooling with sea water
3. Control 4 “self-optimizing” variables:
   - Future work will focus on this

Acknowledgements

This work has been done as part of the The Gas Technology Center, NTNU-SINTEF. Funding from the Norwegian Research Council is gratefully acknowledged.