Earlier Lecture

• In the earlier lecture, we have seen Kapitza & Heylandt systems which are the modifications of the Claude System.

• Collins system is an extension of the Claude system to reach lower temperatures (for example LHe) wherein two to six expansion devices are used.

• For a given pressure condition, the yield $y$ and $W/m_f$ depends on the fraction of gas diverted through expander 1 and 2 ($x_1$ and $x_2$) and the temperature at the inlet to the expanders.
Topic: Gas Liquefaction and Refrigeration Systems (contd)

- Components of Gas Liquefaction and Refrigeration Systems
  - Heat Exchangers
  - Compressors and Expanders

- LN$_2$ and LHe plant videos

- System Comparison

- Summary
Introduction

• In the earlier lectures, we have seen various Gas Liquefaction and Refrigeration systems.

• The various components like compressors, expanders and heat exchangers are critical to the performance of the system.

• The processes that occur in these components are irreversible and deteriorate the performance of the system.

• Hence, there is a need to study about the various components that are used in these systems.
Heat Exchangers

- Heat exchangers (HX) are the most critical components of any liquefaction system.
- They are used to conserve cold by heat exchange between the high pressure hot gas and the low pressure cold gas.
- We know that when \( \varepsilon < 0.85 \) the L–H system gives \( y = 0 \).
• The requirements of a heat exchanger (HX) are
  • High effectiveness with minimum pressure drop
  • Compact and high heat transfer area/volume
  • Minimum mass with multichannel capabilities
  • High reliability with minimum maintenance

• The different configurations of HX in use are Tubes in tube, Bundled tubes, Finned tube, Plate fin etc.

• The HX can either be a 2 – fluid or a 3 – fluid type and the fluid flow arrangements can be parallel flow, counter flow and cross flow.
Heat Exchangers

- Linde Tube HXs are commonly used in liquefaction systems.
- Linde Concentric tube HX
- Linde multiple tube HX
- Linde concentric tube HX with a wire spacer (turbulator)
- Bundle HX
- Tube(s) in Tube type HX are the simplest of all types in terms of construction.
Heat Exchangers

- These have low cost and are well suited for high pressure applications.

- For large flow rates, 3 tubes are used in a bigger tube or a three channel HX.

- The use of a wire spacer (turbulator) on low pressure side, acts as an extended surface and enhance the heat transfer.
Heat Exchangers

- The Collins HX is as shown.
- It consists of several concentric copper tubes with an edge wound copper helix wrapped in the annular spaces.
- This helix acts as a fin and enhances the heat transfer area.
- In this HX, the high and low pressure streams flow in the inner and outer passages respectively.
Heat Exchangers

Coiled Fin Tube
Heat Exchanger
Heat Exchangers

- Al brazed plate fin HX are most compact HXs with high heat transfer area/volume.

- These can either be single or multi stream HX.

- These are widely used in air separation plants, He plants.

- Critical requirements include thermal design, fabrication (Al brazing).
Heat Exchangers

Plate Fin Heat Exchanger
Compressors

• A Compressor is the source of high pressure gas for any Liquefaction or a Refrigerating System.

• It is also the biggest source of heat generation due to the motor inefficiency and gas compression.

• The two broad classes of compressors are Reciprocating and Rotary Type of compressors.

• Reciprocating type are used for high pressures applications with low flow rate, where as the rotary type are used for high flow rates at moderate pressures.
Compressors

- The losses associated with the compressors are given by Isothermal, Adiabatic, Mechanical and Overall efficiencies.

- Screw and Scroll compressors have a higher isothermal efficiency, low initial cost, more reliability and offer a vibration free performance.

- The compressors being oil lubricated, the oil content in the compressed gas is reduced by the use of Oil Filters.
Compressors

• It is further purified in a gas purifier system consisting of Activated Charcoal Bed (ACB).

• Apart from these, centrifugal compressors have better reliability and are used in liquefaction and separation of gases and Air separation plants.

• Screw compressors are oil lubricated and are generally used for high pressure ratios.
Expanders

• Expanders are used to produce cold in the system. These systems must be well insulated to avoid heat in leak from the ambient.

• On the similar lines to a compressor, Reciprocating type expanders are used for low flow rates and high pressure ratios.

• On the other hand, a Turbo – expander is used for high flow rates and low pressure ratios. The design involves high technology and almost zero maintenance.
Expanders

- The rough schematic of a Turbo – expander is as shown.
- It has an expander (turbine wheel) and a compressor mounted on a common shaft.
- The work produced in expansion across the turbine wheel is used by the compressor.
Expanders

- To ensure high efficiency for high mass flow rates, Turbo expanders in small diameters are operated at very high speeds (3000-4000 rps).

- However, efficiency degrades due to various non-ideal conditions like leakage around turbine wheel, windage loss, finite number of flow passages etc.

- Turbine Bearings, Balancing and manufacturing are still matter of research.
Liquid Helium Plant

IP Buffer

Main Comp.

Cold Box

Expander HX, Valves, Piping, Sensors, Insulation

HP

LP

G He

Mist He

L He

Users

Purifier

Liquid Receiver

Pure Cylinder

Impure Cylinder

Gas Bag

Pure Cylinder

Dewar Vessel

Recovery Comp.
Liquid Helium Plant

• The following are the details of LHe Plant at the IIT Bombay.

• Specifications of LHe Plant
  • Model : Linde 1410
  • Output : 15 lit/hr

• Liquefier
  • Inlet : 17 bar
  • Expander : Reciprocating Type
  • RPM : 230
  • Liquid Nitrogen cooled (optional)
Liquid Helium Plant

• Specifications of LHe Plant
  • **Main Compressor**
    • Hermetically sealed Screw Compressor
    • Chilled water cooled and oil lubricated
    • Suction : 1.33 bar, Delivery : 18 bar
    • Power Input : 80 kW
  • **Recovery Compressor**
    • 4 – Stage reciprocating type
    • Air cooled and oil lubricated
    • Suction : ~ ambient, Delivery : 17 bar
    • Power Input : 11 kW
Liquid Helium Plant

- Specifications of LHe Plant
  - Buffer volume: 1 m³
  - Quad Cylinder Pressure: 133.3 bar

- Chiller (Main Compressor)
  - Make: Blue Star
  - Temperature: 11 to 15 deg C.

- User
  - Physical Property Measurement System (PPMS)
  - Consumption: 15 lit/day
Liquid Helium Plant

• The following is the video footage of LHe plant at the IIT Bombay.

• Liquid Helium Plant
The following are the details of LN$_2$ Plant at the IIT Bombay.

- Stirling cryocooler with Helium as working fluid used to liquefy Nitrogen.
- Specifications of LN$_2$ Plant
  - Model: Stirling Cryogenics
  - Output: 50lit/hr
    - **Air Compressor**
      - Power: 25 kW
      - Speed: 2945 RPM
      - Pressure: 15 bar (max)
Liquid Nitrogen Plant

• Specifications of LN$_2$ Plant
  • **Cryogenerator**
    • Motor power : 45 kW
    • Speed : 1480 RPM
    • Operating Temp : 67 K - 200 K
    • Capacity : 4.4kW @ 66 K
    • Working Fluid : He, 99.9999%
    • Mean Pressure : 22 bar

• **Chiller**
  • Cooling Capacity : 48 kW
  • Condenser : Water cooled
Liquid Nitrogen Plant Layout

- Compressor
- Air Vessel
- Air Dryer
- Pressure Swing Adsorption System
- Cryogenerator
- Liquid Nitrogen
- Storage Vessel 2000 lit.
- Oxygen enriched Air
- N₂ Gas
- N₂ Buffer Vessel
- Cooling water
Liquid Nitrogen Plant

- The following is the video footage of $\text{LN}_2$ plant at the IIT Bombay.

- Liquid Nitrogen Plant
System Comparison

• The following parameters are kept constant to compare the various Liquefaction systems studied so far.
  • Working fluid : Nitrogen
  • Initial condition : 1 atm and 300 K
  • Final condition :
    • 200 atm (Ideal, L – H, Dual pressure L – H, Precooled L – H)
    • 40 atm (Claude, Kapitza, Heylandt)
    • 15 atm (Collins for Helium)

• All the equipments are assumed to be prefect.
## System Comparison

**Working Pressure: 1 atm → 200 atm, N\textsubscript{2}**

<table>
<thead>
<tr>
<th>Liquefaction System</th>
<th>y</th>
<th>W/m\textsubscript{f}</th>
<th>FOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Ideal Thermodynamic Cycle</td>
<td>1.000</td>
<td>767.0</td>
<td>1.000</td>
</tr>
<tr>
<td>2 Simple Linde – Hampson System</td>
<td>0.069</td>
<td>6840</td>
<td>0.112</td>
</tr>
<tr>
<td>3 Precooled Linde – Hampson System, T\textsubscript{3} = 243 K</td>
<td>0.103</td>
<td>4633</td>
<td>0.165</td>
</tr>
<tr>
<td>4 Linde Dual – Pressure System, P\textsubscript{i} = 50 atm, r = 0.8</td>
<td>0.051</td>
<td>3866</td>
<td>0.198</td>
</tr>
</tbody>
</table>
## System Comparison

**Working Pressure : 1 atm \rightarrow 40 \text{ atm, } N_2**

<table>
<thead>
<tr>
<th>Liquefaction System</th>
<th>y</th>
<th>W/m\text{f}</th>
<th>FOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Claude System, $T_3 = 275$ K, $x = 0.6$</td>
<td>0.27</td>
<td>810.5</td>
<td>0.946</td>
</tr>
<tr>
<td>6 Kapitza System, $T_3 = 275$ K, $x = 0.6$</td>
<td>0.268</td>
<td>817.2</td>
<td>0.938</td>
</tr>
<tr>
<td>7 Heylandt System, $x = 0.5$</td>
<td>0.257</td>
<td>895.3</td>
<td>0.856</td>
</tr>
</tbody>
</table>

**Working Pressure : 1 atm \rightarrow 15 \text{ atm, } He**

<table>
<thead>
<tr>
<th>Liquefaction System</th>
<th>y</th>
<th>W/m\text{f}</th>
<th>FOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 Collins System, $T_3 = 60$ K, $T_5 = 15$ K, $x_1 = 0.4$, $x_2 = 0.2$</td>
<td>0.066</td>
<td>25230</td>
<td>0.271</td>
</tr>
</tbody>
</table>
• A system which produces cold or maintains such low temperatures is called as a Refrigerating System. This process is called as Refrigeration.

\[
\frac{\partial T}{\partial p}_h
\]

• This ratio \( \frac{\partial T}{\partial p}_h \) is called as J – T coefficient.

\[
\frac{\partial T}{\partial p}_s
\]

• The ratio \( \frac{\partial T}{\partial p}_s \) is called as Isentropic Expansion Coefficient.

• An ideal gas does exhibit a cooling effect, when it undergoes an isentropic expansion unlike the J – T expansion.
Summary

• Isenthalpic expansion of gases such as Hydrogen and Helium does not produce cold when expanded from room temperature.

• Where as gases like oxygen and nitrogen result in cooling when expanded isenthalpically.

• The isentropic expansion always results in cooling irrespective of its $T_{INV}$. 
Summary

- Various Liquefaction systems seen so far are
  - Ideal Thermodynamic system
  - Linde – Hampson System
  - Precooled Linde – Hampson System
  - Dual – Pressure Linde System
  - Claude System
  - Kapitza System
  - Heylandt System
  - Collins System

- Heat exchangers, Compressors, Expanders
Thank You!