CRYOGENIC ENGINEERING
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Lecture No - 17

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 $\mathbf{W / m_f}$ depends on the fraction of gas diverted through expander **1** and **2** ($\mathbf{x_1}$ and $\mathbf{x_2}$) and the temperature at the inlet to the expanders.

Outline of the Lecture

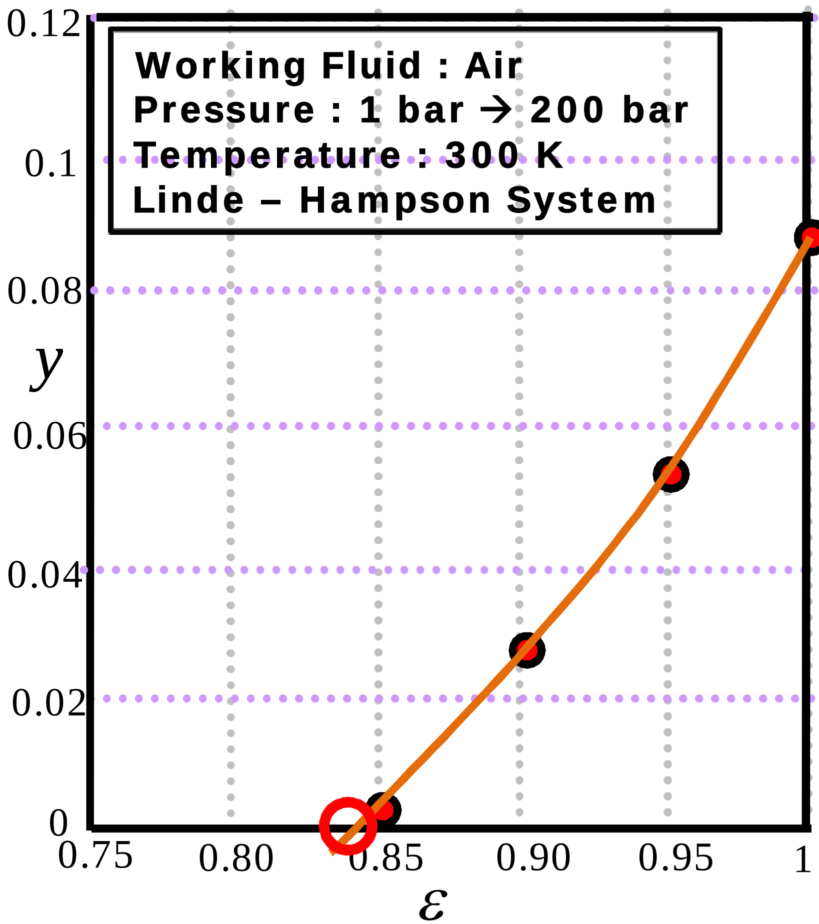
Topic : Gas Liquefaction and Refrigeration Systems (contd)

- 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**.

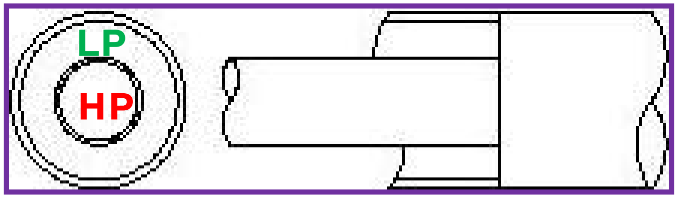
Heat Exchangers

- 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

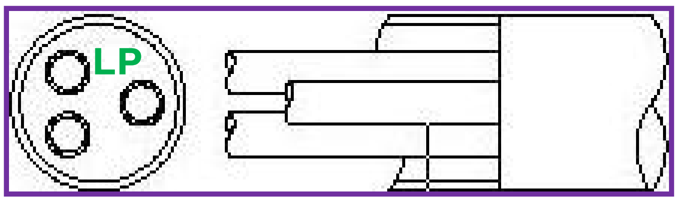
- The different configurations of HX in use are Tubes in tube, Bundled tubes, Finned tube, Plate fin etc.

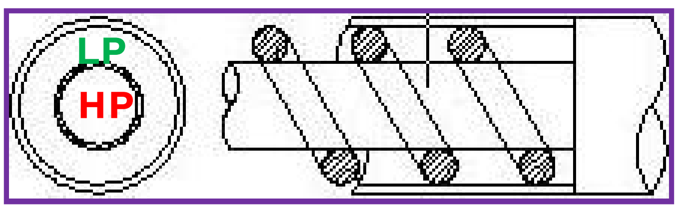
- The HX can either be a **2 – fluid** or a **3 – fluid** type and the fluid flow arrangements can be parallel flow, counter flow and cross flow.

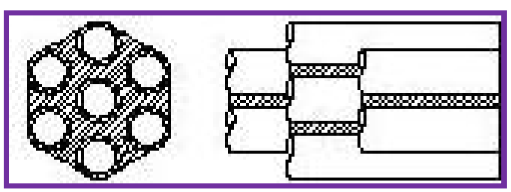
Heat Exchangers



- Linde Tube HXs are commonly used in liquefaction systems.



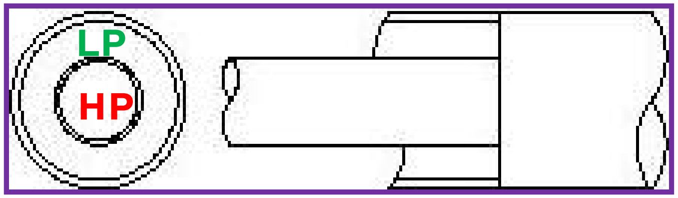


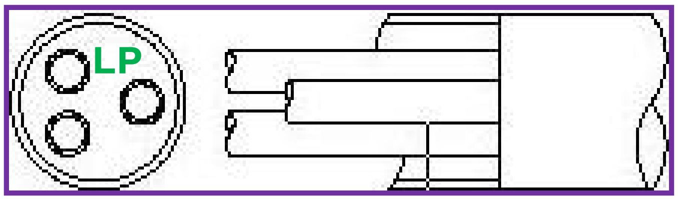


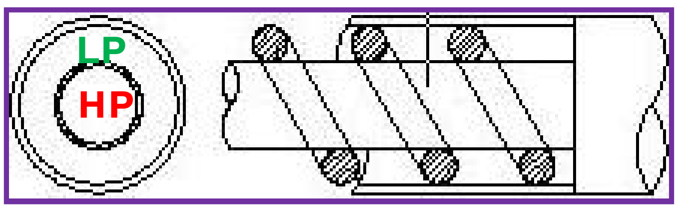
- Linde Concentric tube HX
- Linde multiple tube HX
- Linde concentric tube HX with a wire spacer (turbulator)
- Bundle HX

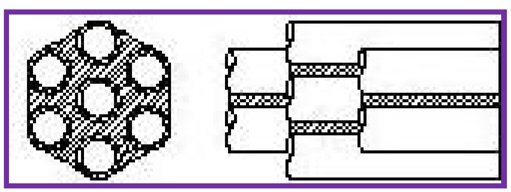
- Tube(s) in Tube type HX are the simplest of all types in terms of construction.

Heat Exchangers



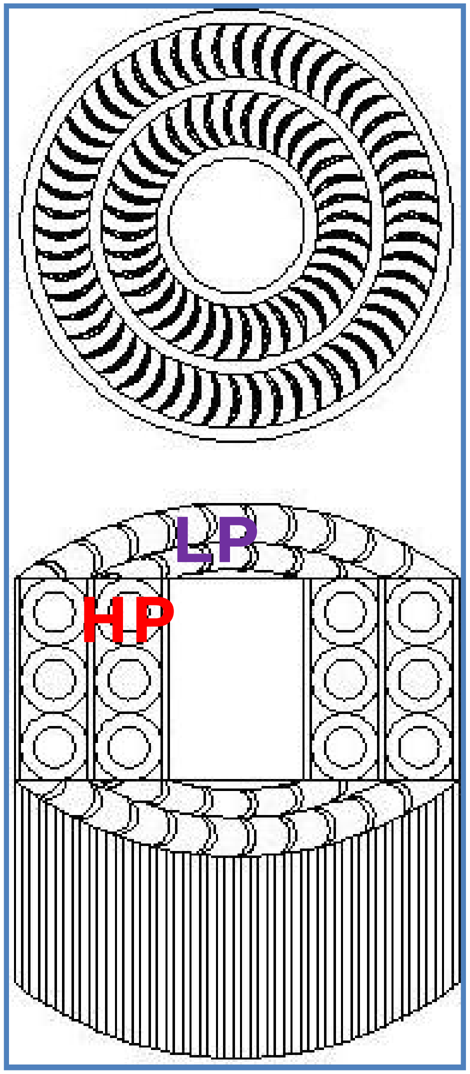






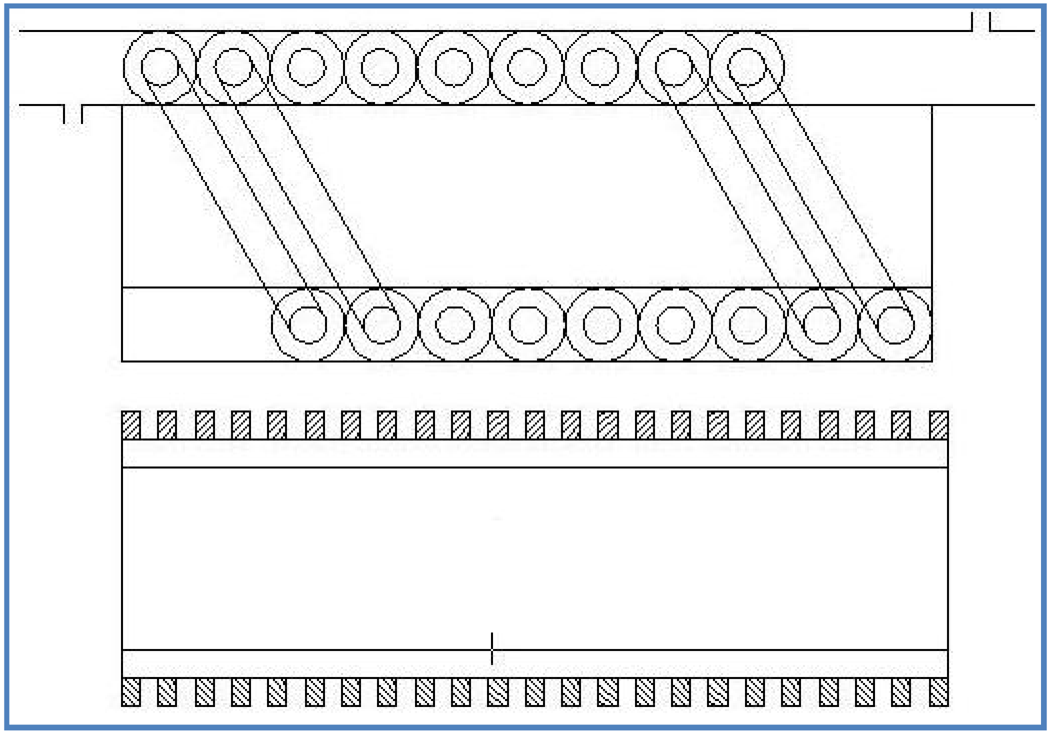
- These have low cost and are well suited for high pressure applications.
- For large flow rates, 3 tubes are used in a bigger tube or a three channel HX.
- The use of a wire spacer (turbulator) on low pressure side, acts as an extended surface and enhance the heat transfer.

Heat Exchangers



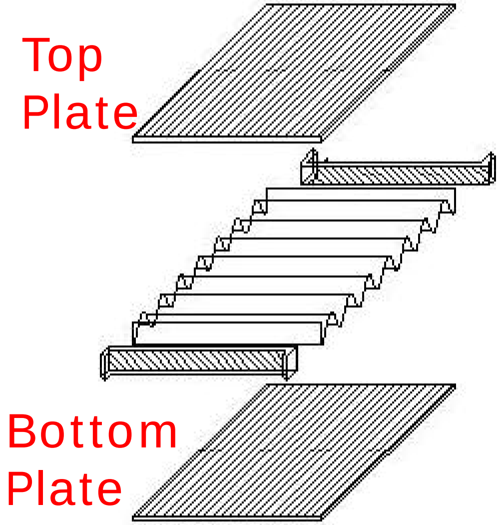
- The Collins HX is as shown.
- It consists of several concentric copper tubes with an edge wound copper helix wrapped in the annular spaces.
- This helix acts as a fin and enhances the heat transfer area.
- In this HX, the high and low pressure streams flow in the inner and outer passages respectively.

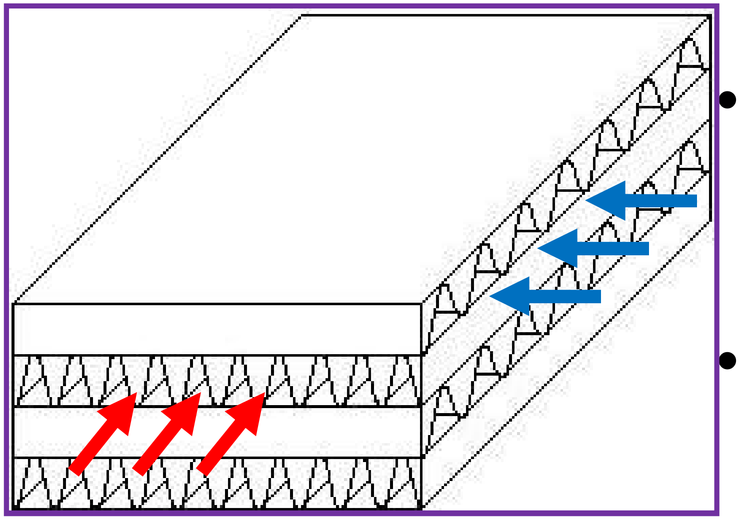
Heat Exchangers



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

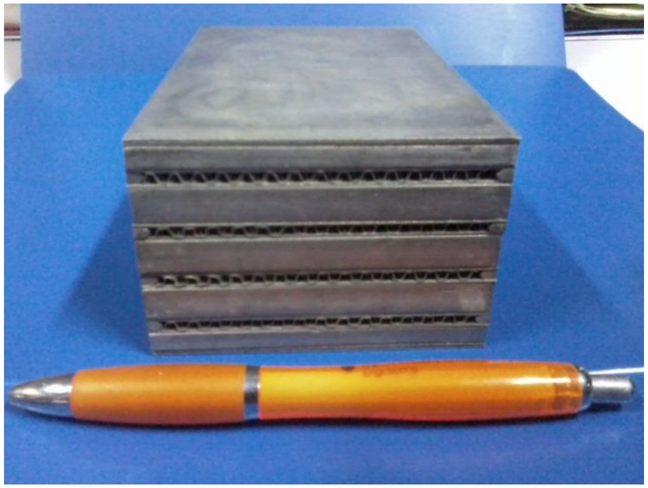
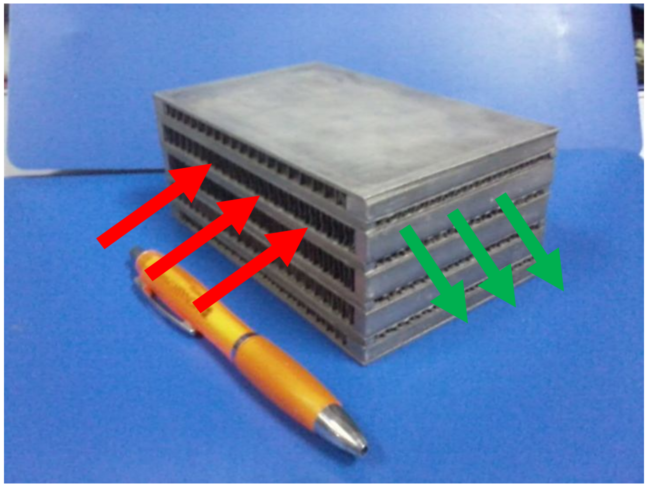


Plate Fin Heat Exchanger



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.

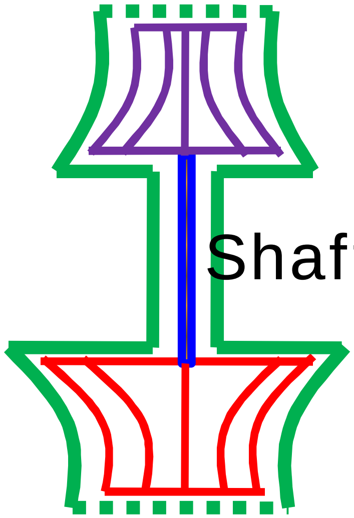
Expanders

- 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

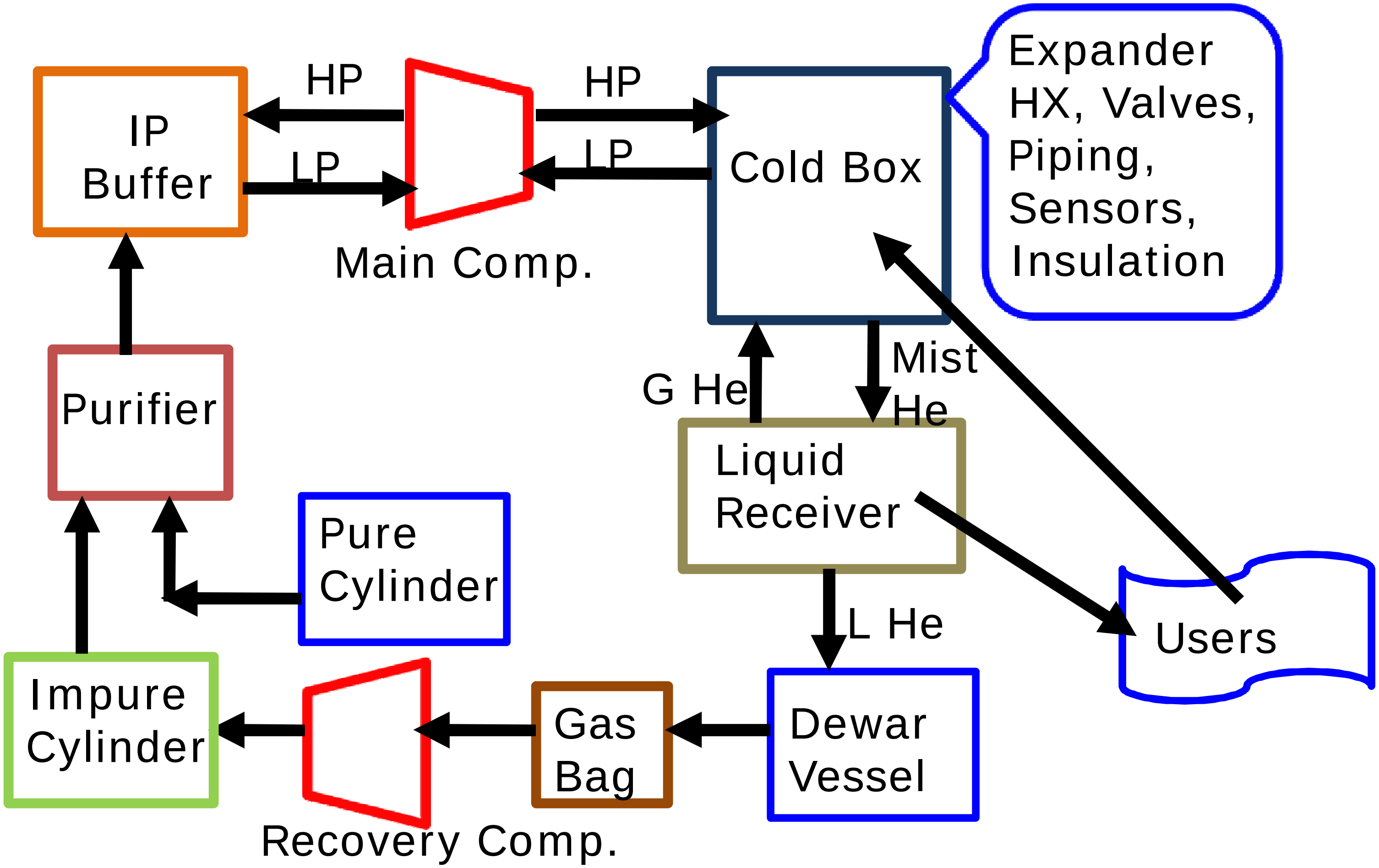


- The rough schematic of a Turbo – expander is as shown.
- It has an expander (turbine wheel) and a compressor mounted on a common shaft.
- The work produced in expansion across the turbine wheel is used by the compressor.

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



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 m^3
  - 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**

Liquid Nitrogen Plant

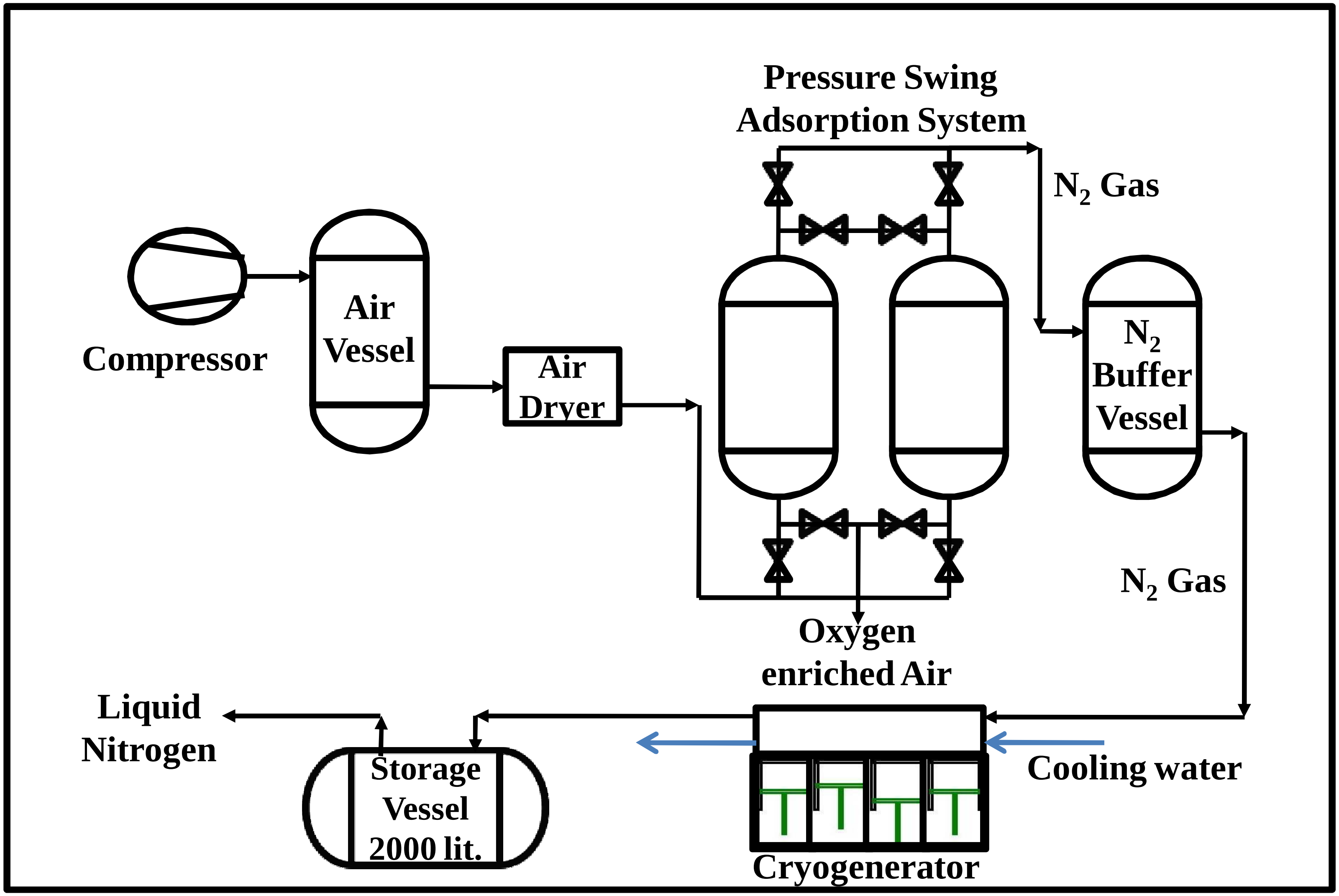
- The following are the details of **LN_2** Plant at the IIT Bombay.

- 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



Liquid Nitrogen Plant

- The following is the video footage of **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_2

	Liquefaction System	y	W / m_f	FOM
1	Ideal Thermodynamic Cycle	1.000	767.0	1.000
2	Simple Linde – Hampson System	0.069	6840	0.112
3	Precooled Linde – Hampson System, T_3 = 243 K	0.103	4633	0.165
4	Linde Dual – Pressure System, P_i = 50 atm, r = 0.8	0.051	3866	0.198

System Comparison

Working Pressure : 1 atm → 40 atm, N_2

	Liquefaction System	y	W / m_f	FOM
5	Claude System, T_3 =275 K, x = 0.6	0.27	810.5	0.946
6	Kapitza System, T_3 =275 K, x = 0.6	0.268	817.2	0.938
7	Heylandt System, x = 0.5	0.257	895.3	0.856

Working Pressure : 1 atm → 15 atm, He

	Liquefaction System	y	W / m_f	FOM
8	Collins System, T_3 = 60 K, T_5 = 15 K, x_1 = 0.4, x_2 = 0.2	0.066	25230	0.271

Summary

- A system which produces cold or maintains such low temperatures is called as a Refrigerating System. This process is called as Refrigeration.
- This ratio $\left(\frac{\partial T}{\partial p}\right)_h$ is called as J – T coefficient.
- The ratio $\left(\frac{\partial T}{\partial p}\right)_s$ 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 expander from room temperature.
- Where as gases like oxygen and nitrogen result in cooling when expanded isenthalpicaly.
- The isentropic expansion always results in cooling irrespective of its $\mathbf{T_{INV}}$.

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!