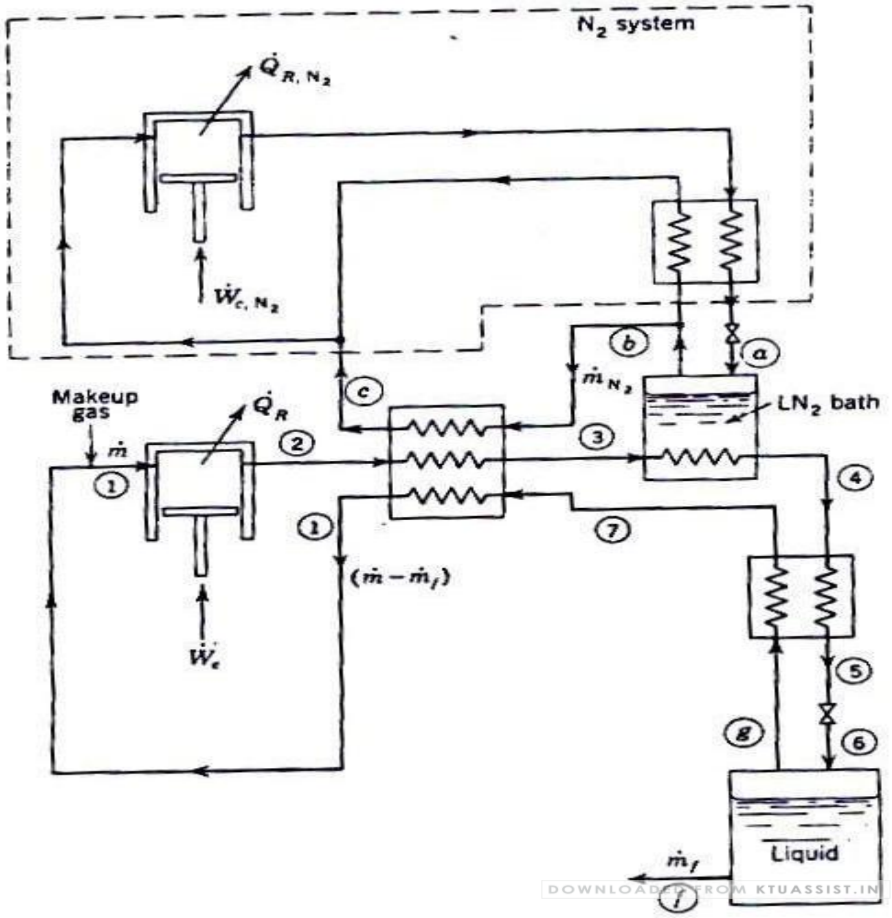
SNS COLLEGE OF TECHNOLOGY
(An Autonomous Institution)
COIMBATORE–35

DEPARTMENT OF AEROSPACE ENGINEERING

SPACE PROPULSION – Unit III
CRYOGENIC ENGINEERING

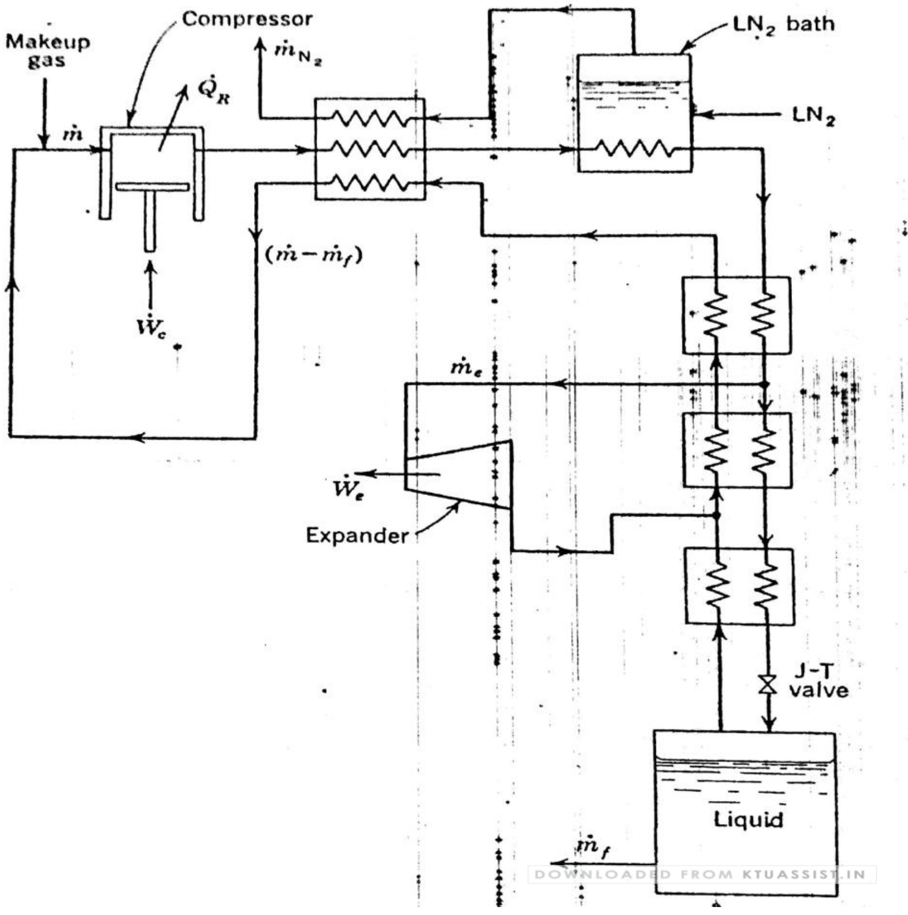
Liquid-nitrogen precooled linde –hampson system for neon or nitrogen

- A liquid-nitrogen-precooled Linde-Hampson system is shown schematically in figure.
  - For small laboratory liquefiers, the nitrogen-liquefaction subsystem would be replaced by a small storage vessel from which liquid nitrogen could be withdrawn and passed through the precooling bath, and the vapor discharged through the three-channel heat exchanger to the atmosphere.
- Any fluid that has a triple point temperature below that of the MIT of neon and hydrogen can be used as precoolant.
- Such fluids are fluorine,oxygen,air,methane ,argon,nitrogen.Nitrogen is the best suited.



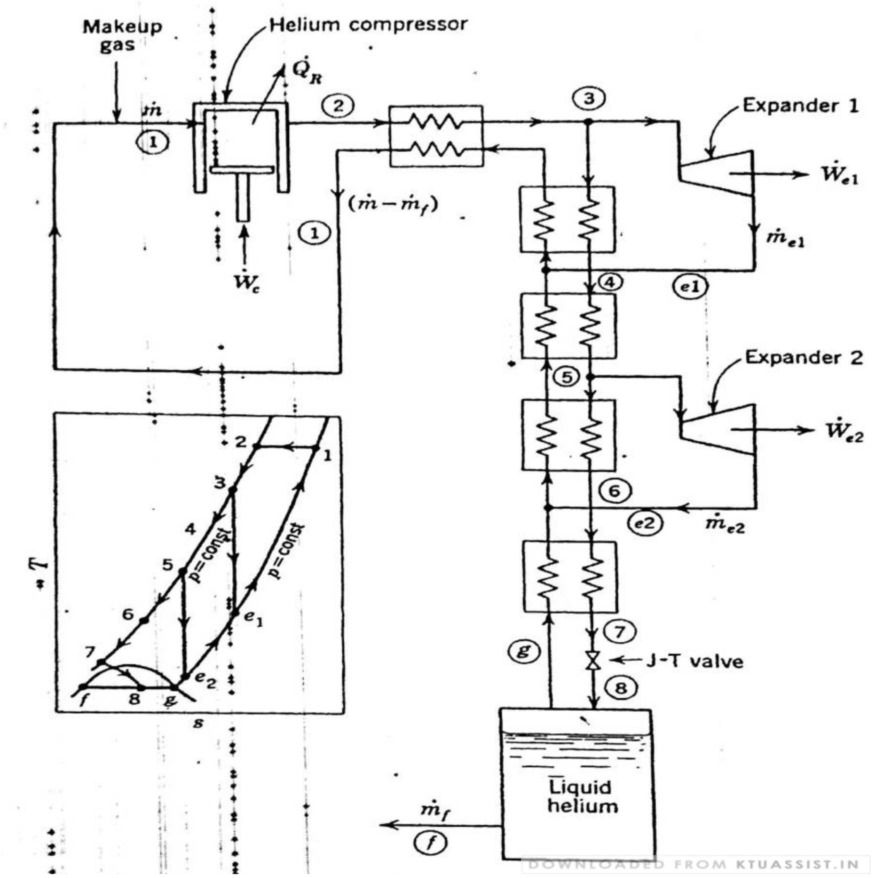
Precooled Claude System for Hydrogen or Neon

- The Claude system do not depend on the expansion valve to produce low temperatures.
- Hence Claude system can be used for hydrogen or neon without modification.
- If a liquid nitrogen precooling bath is used with the Claude system, the performance is further improved.(50-75% higher than that of the precooled Linde Hampson system)
- With the liquid-nitrogen precooling, the Claude system for hydrogen production has a figure of merit 50 to 75 percent higher than that of the precooled Linde-Hampson system.

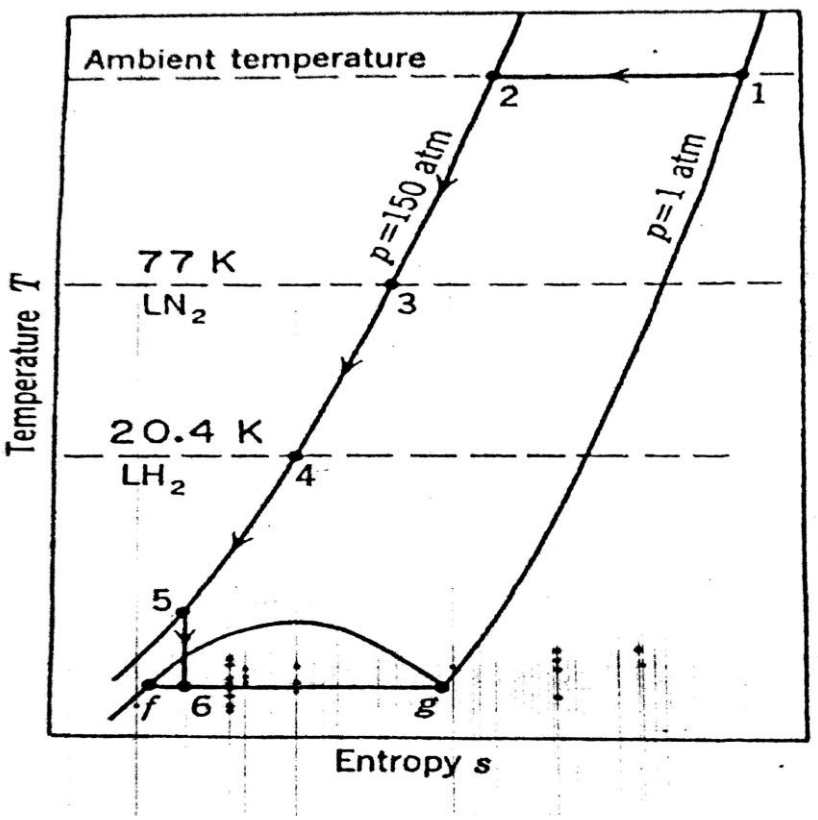


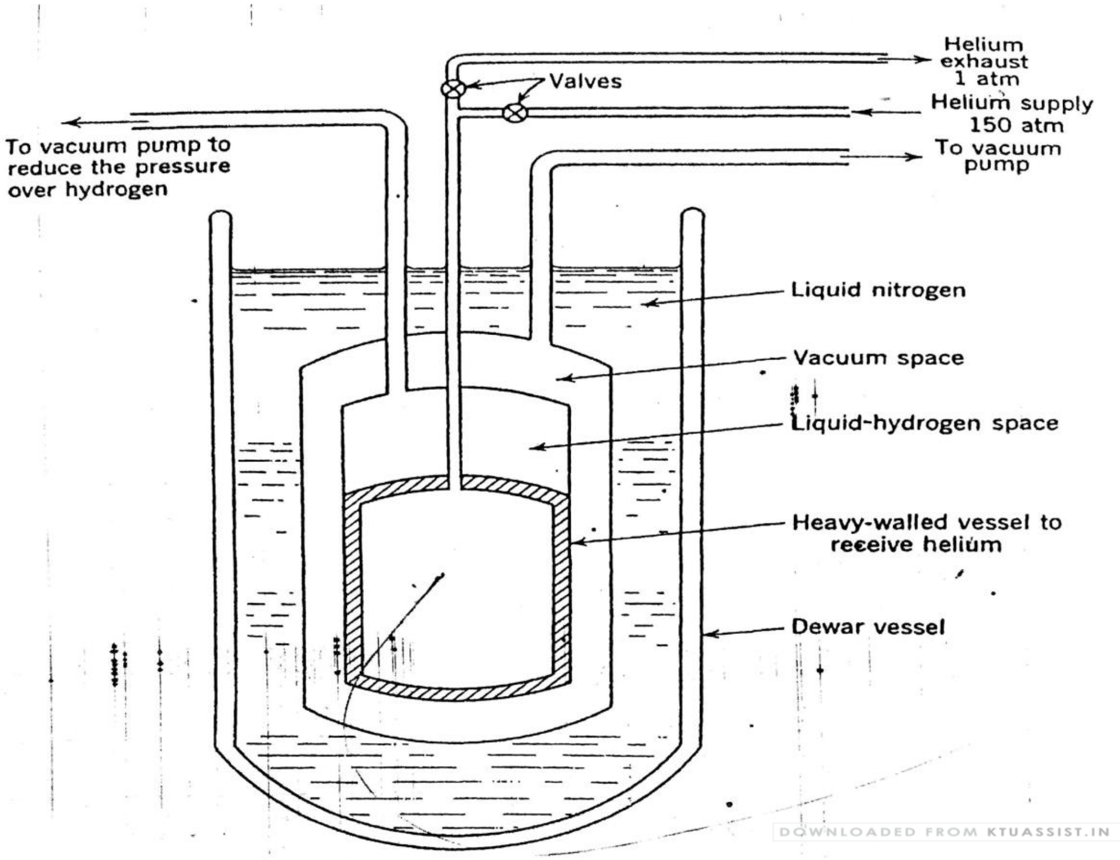
Collins helium-liquefaction system

- As for the case of hydrogen and neon, the precooled Linde-Hampson system may be used to liquefy helium by using liquid hydrogen as the precoolant.
- This type of precooled system was used in several of the earlier helium liquefiers.
- One of the milestones in cryogenic engineering was the design and development of a helium liquefier by Samuel C. Collins at the Massachusetts Institute of Technology.
- This liquefier is an extension of the Claude system, as shown in Fig.
- Depending upon the helium inlet pressure, from two to five expansion engines are used in this system.



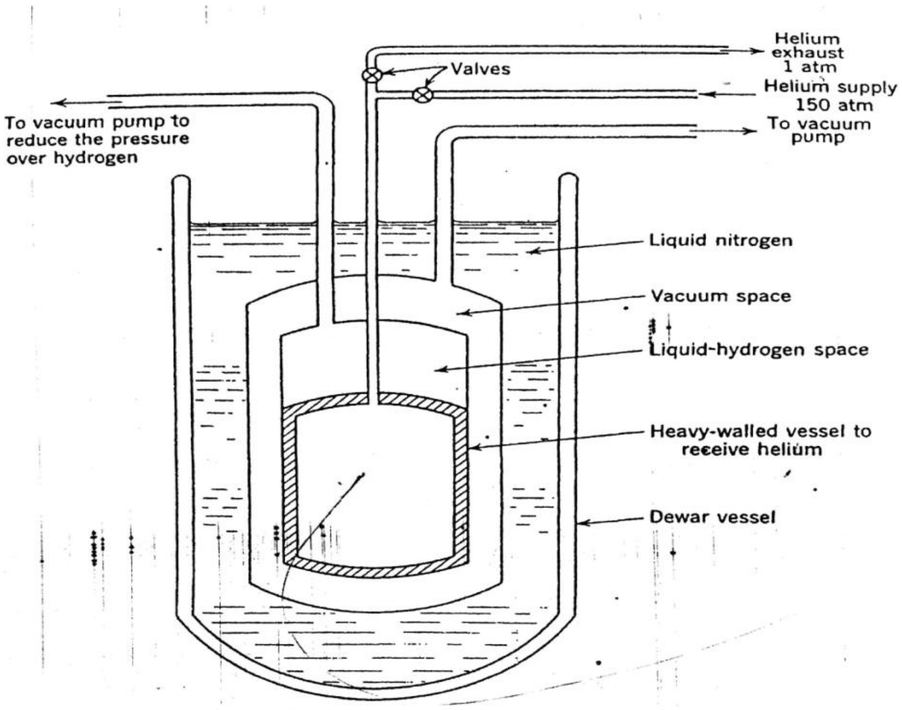
Simon helium-liquefaction system





Simon helium-liquefaction system

- One of the methods used to liquefy small quantities of helium is the Simon liquefaction system (Pickard and Simon 1948).
- This system does not operate as a steady flow system,but produces helium in batches.
- Process 1-2:Helium gas is introduced to the heavy wall container at a pressure on the order of 10 Mpa to 15 Mpa and at ambient temperature.
- Process 2-3:Liquid nitrogen is introduced into the enclosing bath.This process cools the entire container and its contents to liquid nitrogen temperature(77K).
- During this process the vacuum space may be filled with helium gas at atmospheric pressure to act as a heat transfer medium.



CRITICAL COMPONENTS OF LIQUEFACTION SYSTEMS

1. HEAT EXCHANGERS
2. COMPRESSORS
3. EXPANDERS

Types of Heat Exchangers used in cryogenic Systems

- 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.
- 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 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.**

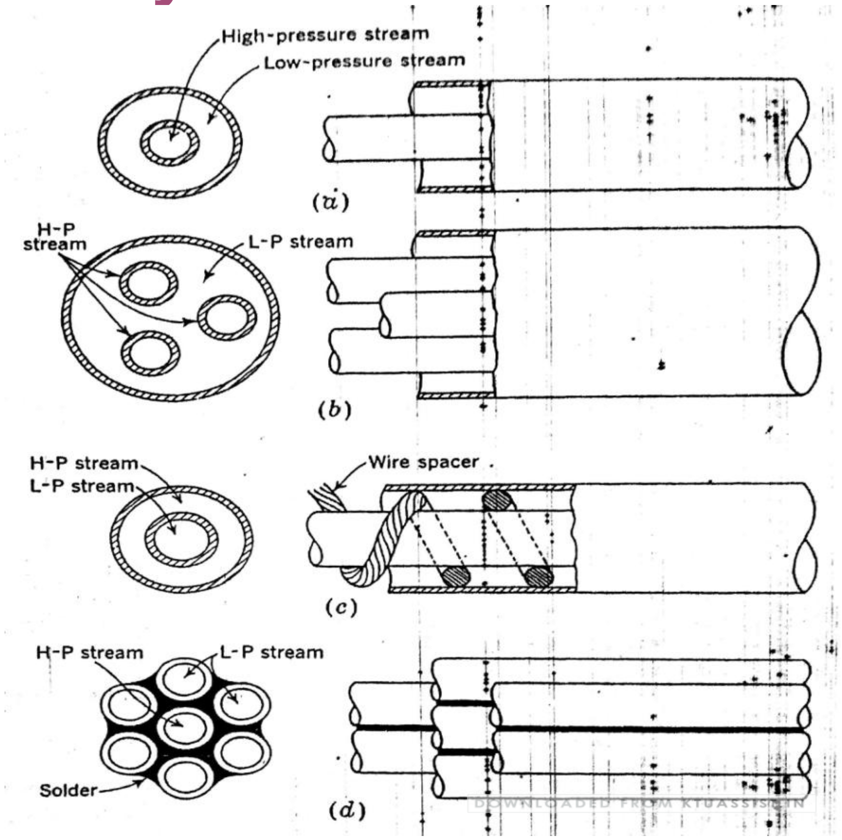
Types of Heat Exchangers used in cryogenic Systems

The different types of Heat exchanger (HX) in use are

- Linde Heat exchanger (for smaller systems)
    - Linde concentric tube heat exchanger(tube in tube)
    - Linde multiple tube heat exchanger
    - Linde Concentric tube heat exchanger with wire spacer
    - Bundled tube heat exchanger
- Giaque Hampson heat exchanger
- Collins heat exchanger
- Plate fin heat exchanger

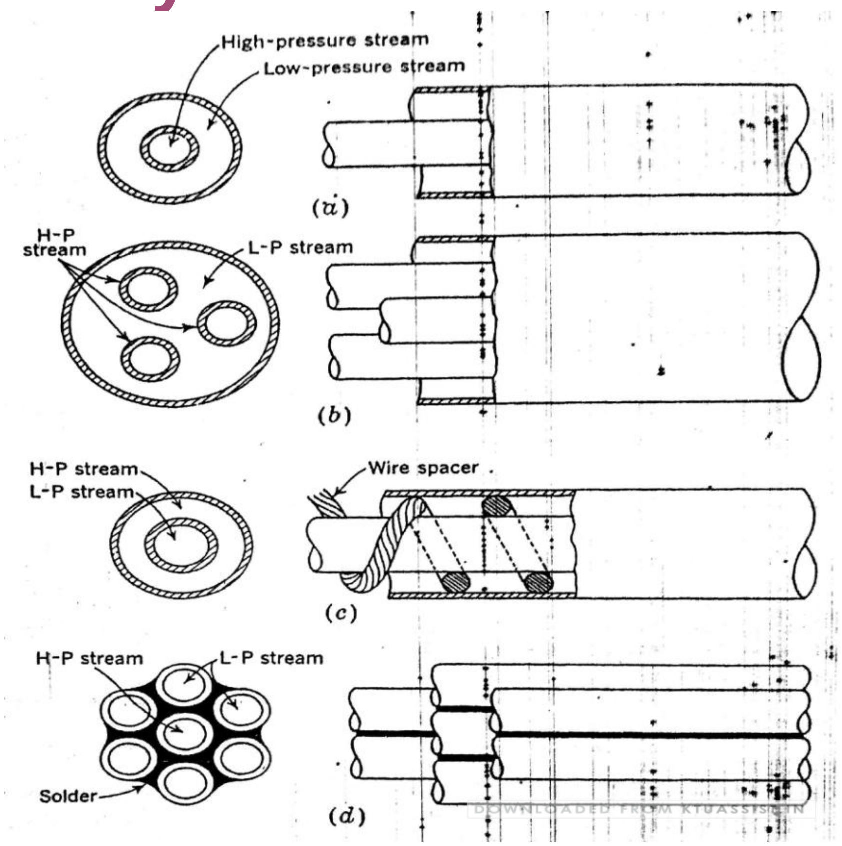
Types of Heat Exchangers used in cryogenic Systems

- **LINDE TUBE HEAT EXCHANGERS** are commonly used in smaller size liquefaction systems.
  a. Linde concentric tube heat exchanger(tube in tube)
  b. Linde multiple tube heat exchanger
  c. Linde Concentric tube heat exchanger with wire spacer
  d. Bundled tube heat exchanger
- **Concentric tube(Tube in Tube type) HX(a):** are the simplest of all types in terms of construction.This single tube heat exchanger is the original type used by Linde in his early liquefaction system.
- This heat exchanger consists of a small inner tube in which the warm high pressure gas flows concentric to a larger tube in which the cold low pressure gas returns.
- The double tube is wound in a large helix to conserve space, and the entire unit is well insulated



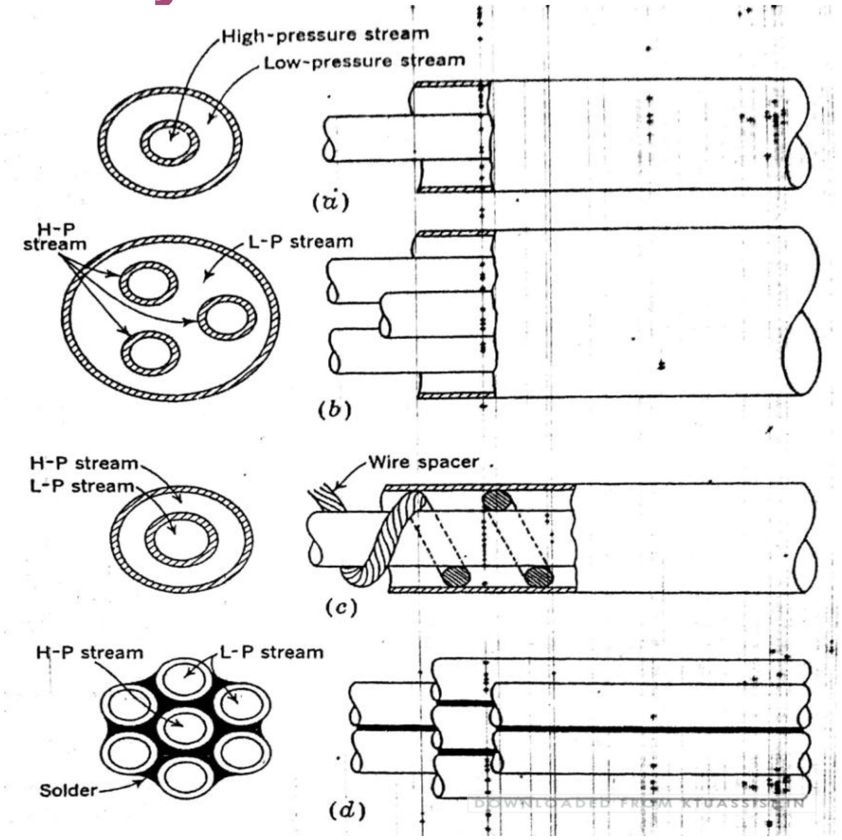
Types of Heat Exchangers used in cryogenic Systems

- **Linde multiple tube heat exchanger(b):** in systems where high pressure stream flow rate is large or in which 3-channel heat exchangers are used,a multiple tube Linde HX may be used.
- The high pressure and intermediate pressure streams flow in the smaller tubes,while the low pressure return stream flows around the smaller tubes within the larger tube.
- **Linde Concentric tube heat exchanger with wire spacer(c):** The use of a wire spacer (turbulator) enhances the heat transfer,though at the cost of an unwanted pressure drop.
- The wire acts as a “turbulator” to cause a more turbulent flow in the low pressure stream.
- If the wire is soldered onto the inner tube,it acts as an extended surface to increase the effective area of the outside of the inner tube.



Types of Heat Exchangers used in cryogenic Systems

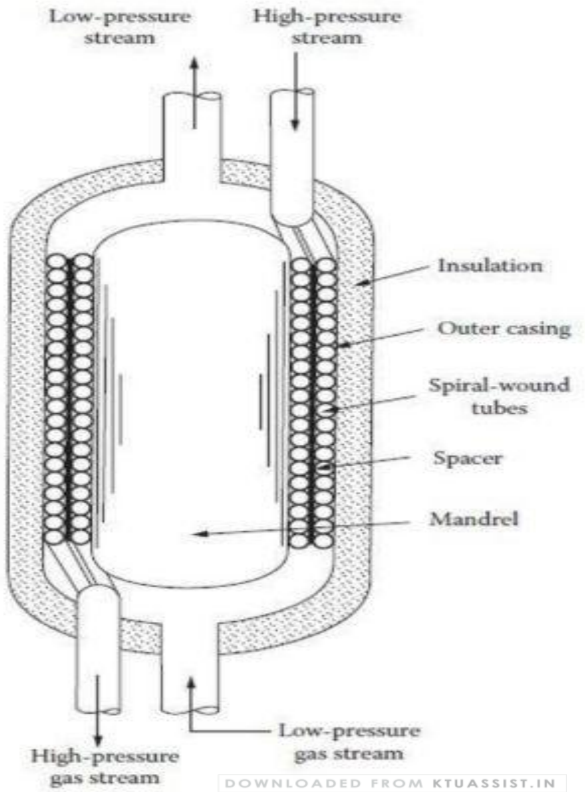
- **Bundled tube heat exchanger(d):** these can be constructed through the use of dip brazing techniques.
- The high pressure stream flows in the center tube while the low pressure return stream flows in the six outer tubes
- All the tubes are firmly soldered together to ensure good thermal contact between the streams.



Types of HX

GIAUQUE HAMPSON HEAT EXCHANGER

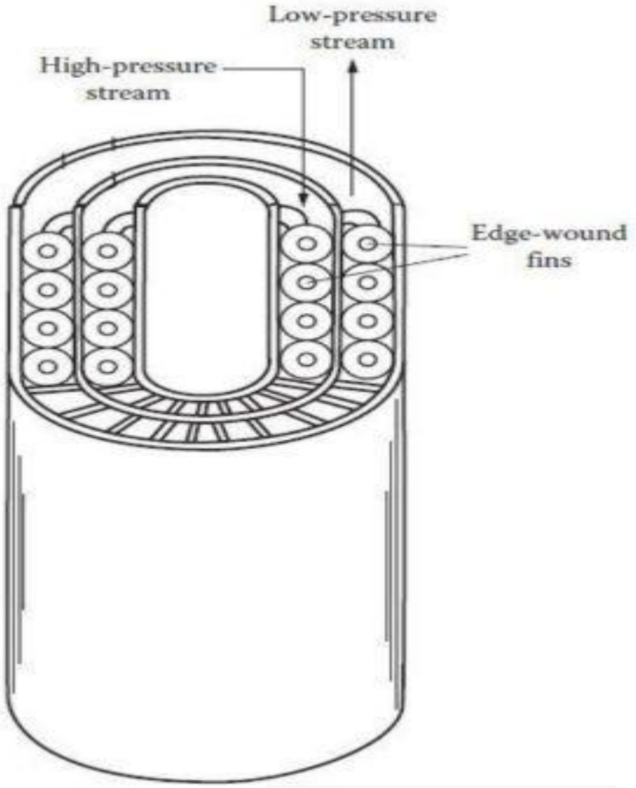
- The classical heat exchanger for large scale liquefaction systems is the Giauque Hampson heat exchanger shown in the figure.
- This HX consists of carefully spaced helixes of small diameter tubes through which the high pressure stream flows.
- The tubes are wrapped around a large cylinder an enclosed in an insulated cylindrical jacket.
- The low pressure return stream flows across the outside of the small tubes in the space between the inner cylinder and the outer jacket.
- It is important to make the spacing of the small tubes uniform;otherwise the low pressure stream will tend to follow the path of widest spacing(or least frictional resistance) and will not be uniformly distributed over the cross section of the exchanger.
- Giauque solved the spacing problem by using punched brass spacer strips to maintain equal tube spacing.



Types of HX

COLLINS HEAT EXCHANGER

- The Collins HX is as shown in the figure
- It is a unique extended surface heat exchanger design.
- It consists of several concentric copper tubes with an edge wound copper helix wrapped in the annular spaces of the tubes
- The helix is soft soldered to both sides of the annular space of the tubes.
- 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.



Types of HX

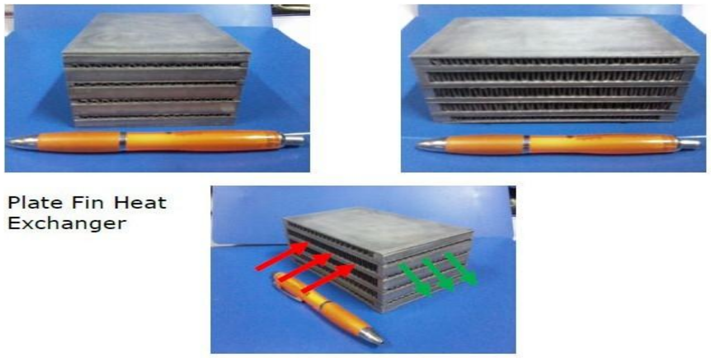


Plate Fin Heat Exchanger

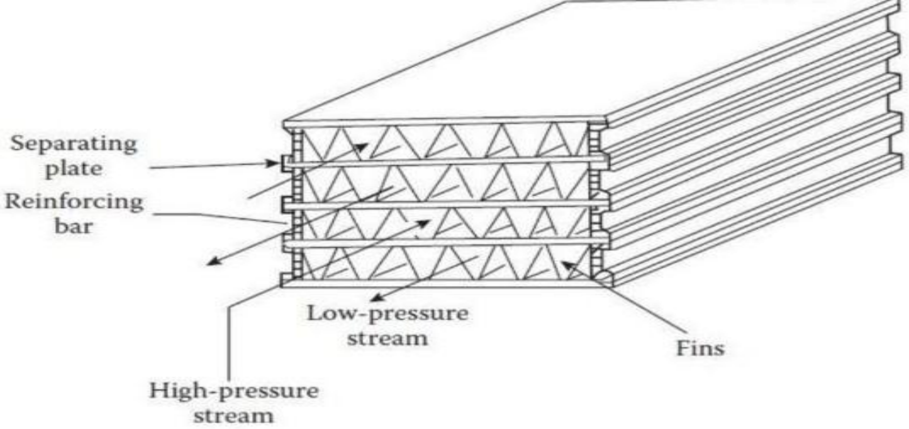
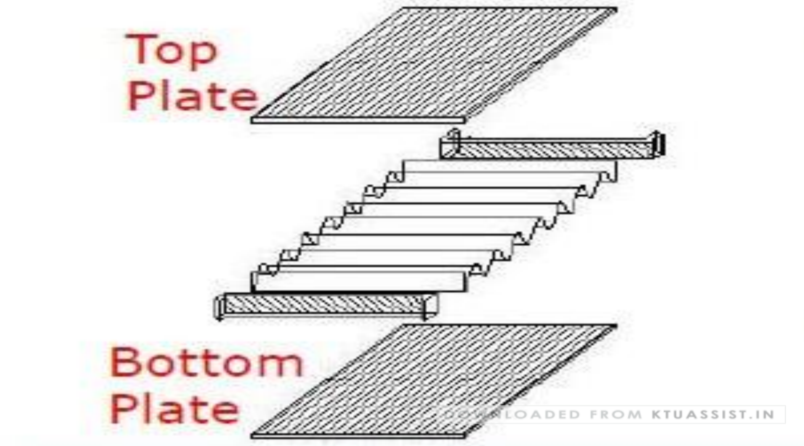


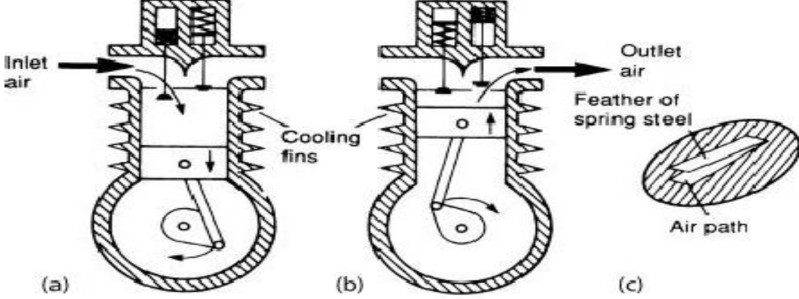
PLATE FIN HEAT EXCHANGER

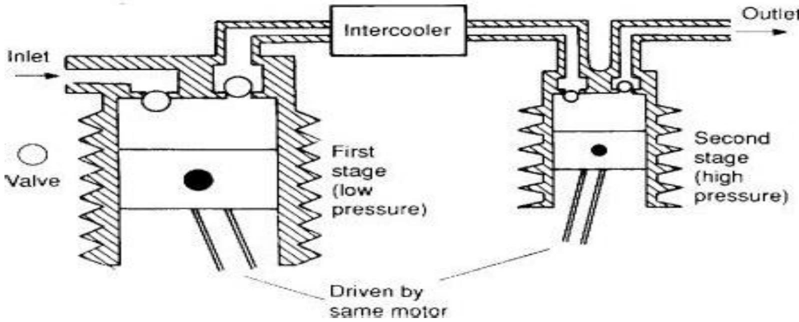
- In any application where space is a premium,the plate fin heat exchanger surface,shown in figure is advantageous.
- The HX surface is formed by dip brazing aluminium plates and corrugated aluminium together.
- Many types of corrugations are used.
- Counterflow,cross flow or multipass arrangements may be used for the individual sandwiches,but counterflow is generally used for cryogenic applications because of the thermal performance for a given HX area.

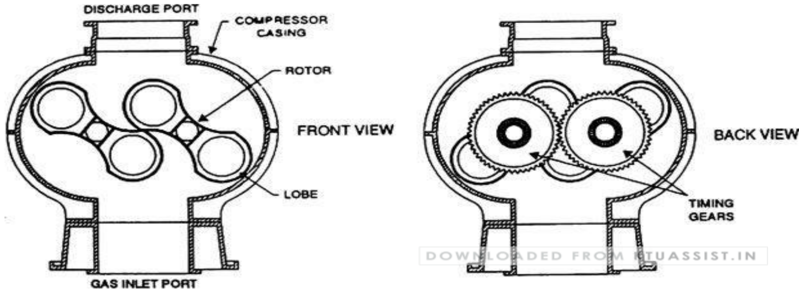


COMPRESSORS

- 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.
- 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.

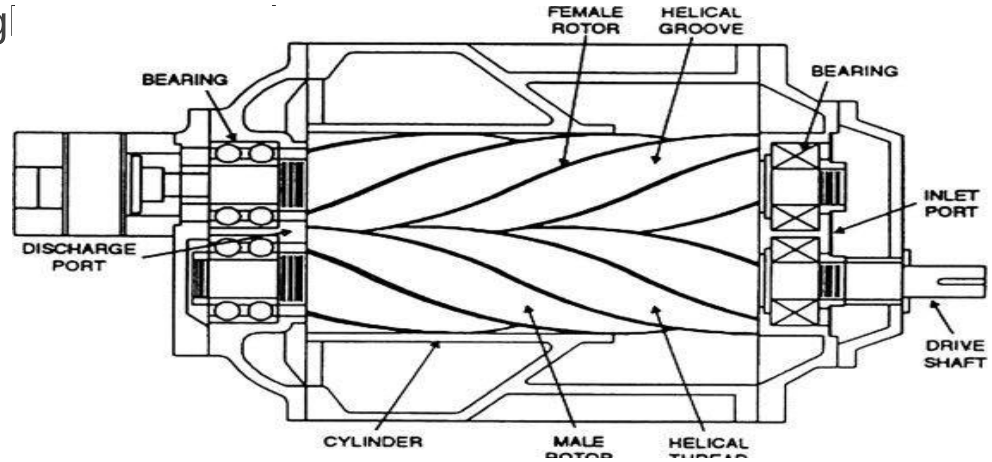


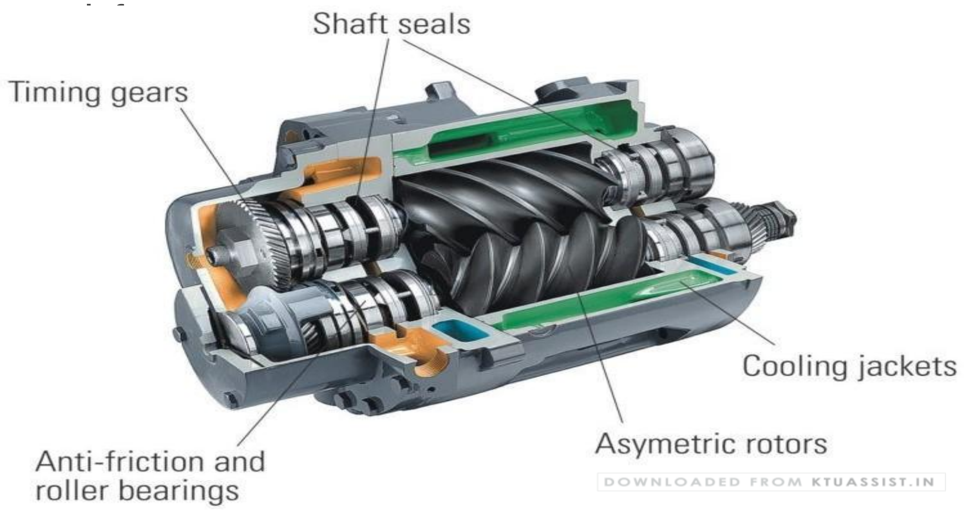




COMPRESSORS

- 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 hig





EXPANDERS

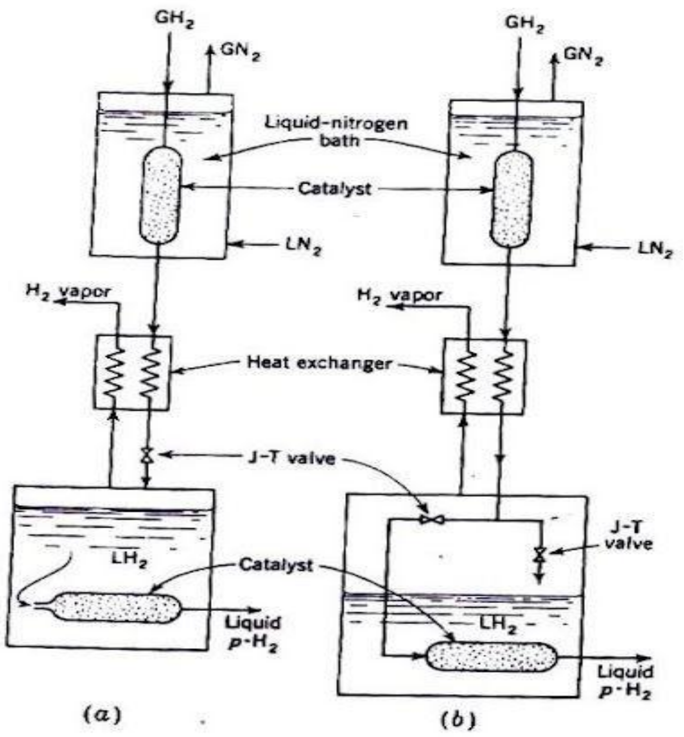
- Expanders are used to produce cold in the system. These systems must be well insulated to avoid heat in leak from the ambient.
- On the similar lines to a compressor, Reciprocating type expanders are used for low flow rates and high pressure ratios.
- On the other hand, a Turbo –expander is used for high flow rates and low pressure ratios. The design involves high technology and almost zero maintenance.
- 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.

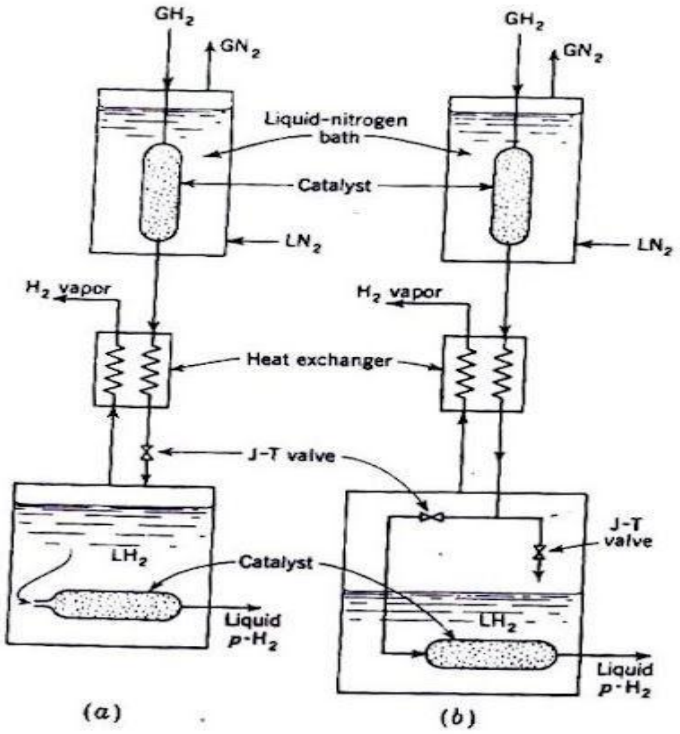
ORTHO TO PARA CONVERSION OF HYDROGEN-The Problem

- We have seen in module 1 that hydrogen can exist in two different forms-parahydrogen and ortho-hydrogen.
- The ortho-para concentration in equilibrium hydrogen depends upon the temperature of the hydrogen. Near room temperature, the composition is practically 75 percent ortho-hydrogen and 25 percent para-hydrogen, whereas at the normal boiling point of hydrogen, the equilibrium composition is almost all para-hydrogen.
- When hydrogen gas is passed through a liquefaction system, the gas does not remain in the heat exchangers long enough for the equilibrium composition to be established at a particular temperature.
- The result is that the fresh liquid has practically the room-temperature ortho-para composition and will, if left alone in the liquid receiver, undergo the exothermic reaction there.



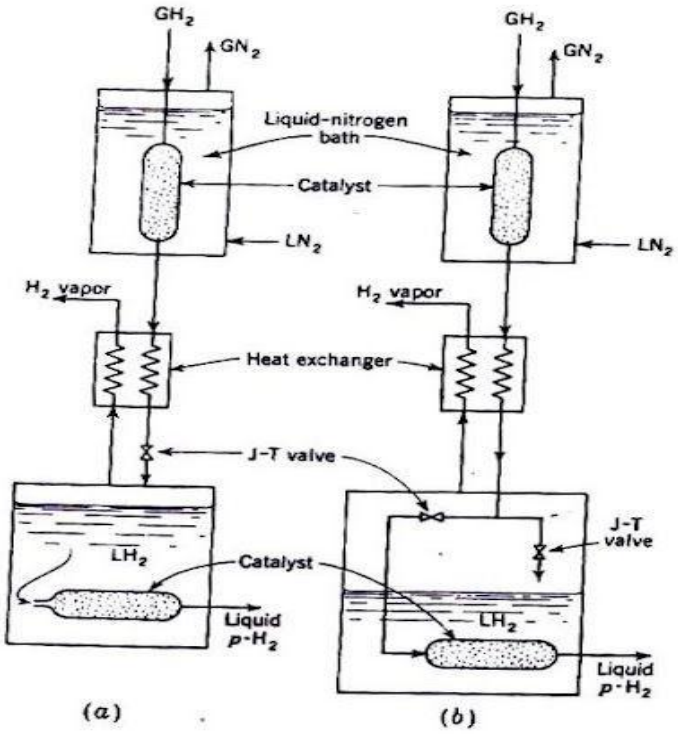
ORTHO TO PARA CONVERSION OF HYDROGEN-The Problem

- The changeover from ortho- to para-hydrogen involves a heat of conversion that is greater than the heat of vaporization of para-hydrogen;
- Therefore, serious boil-off losses will result unless measures are taken to prevent it.
- This is a problem peculiar to hydrogen-liquefaction systems that must be solved in any efficient system



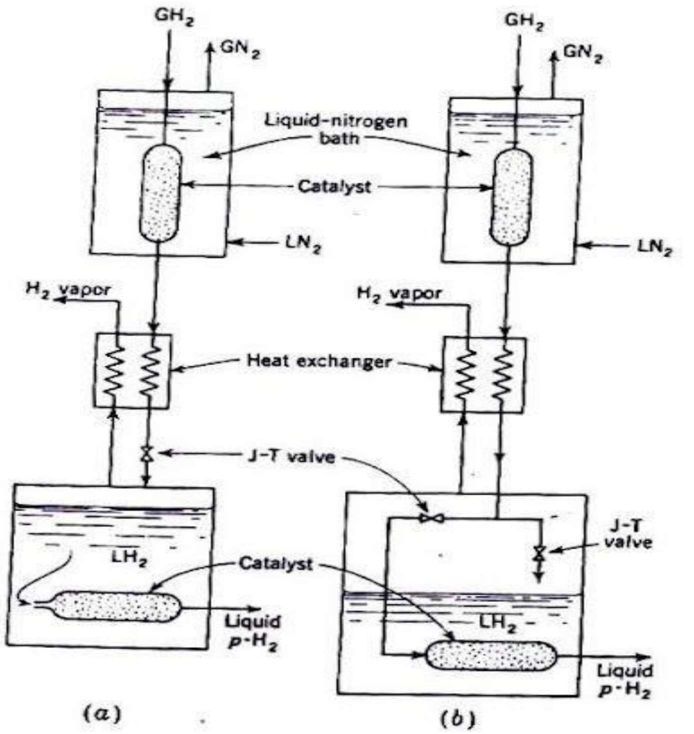
ORTHO TO PARA CONVERSION OF HYDROGEN-The Solution

- A catalyst may be used to speed up the conversion process, while the heat of conversion is absorbed in the liquefaction system before the liquid is stored in the liquid receiver.
- Because the heat of conversion results in an increase in liquid evaporated, it is advantageous to carry out as much of the conversion in the liquid-nitrogen bath as possible
- The nitrogen is much less costly to produce than the liquid hydrogen.
- The equilibrium composition at temperature near 70 K (126° R), corresponding to liquid nitrogen boiling under vacuum, is approximately 55 to 60 percent para-hydrogen.
- Thus if the conversion is complete at this temperature, the energy released in the• liquid receiver is reduced by almost one-half.



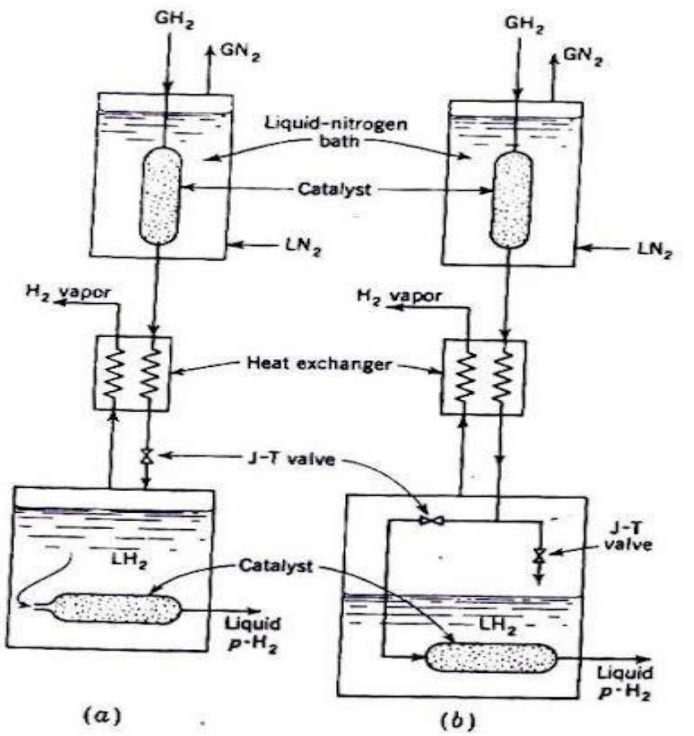
ORTHO TO PARA CONVERSION OF HYDROGEN-The Arrangements

- Two possible arrangements for ortho-para conversion are shown in Figure.
- In the **first arrangement**, the hydrogen' is passed through the catalyst in the liquid-nitrogen bath, expanded through the expansion valve into the liquid receiver, and drawn through a catalyst bed before passing into a storage vessel.
- The hydrogen that is evaporated due to the heat of conversion flows back through the heat exchanger and furnishes additional refrigeration to the incoming stream.



ORTHO TO PARA CONVERSION OF HYDROGEN-The Arrangements

- The **second arrangement** is similar to the first one, except that the high-pressure stream is divided into two parts before the expansion valve.
- One part is expanded through an expansion valve and flows through a catalyst bed immersed in a liquid-hydrogen bath; the converted hydrogen is passed to a storage vessel
- The other part of the high-pressure stream is expanded through another expansion valve into the liquid receiver to furnish refrigeration for the catalyst bed; the vapor is passed back through the heat exchanger to cool down the incoming gas.
- The second arrangement allows approximately 20 percent higher liquid-hydrogen yields compared with the first arrangement.



LOSSES IN GAS LIQUEFACTION SYSTEMS

(NOT IN SYLLABUS,BUT ONCE ASKED IN KTU UNIVERSITY EXAM)

LOSSES IN **RECIPROCATING** COMPRESSORS AND EXPANDERS

- Inlet valve and outlet valve losses
  - Pressure drop occur across the inlet and exhaust valves that decrease the actual pressure range through which gases expand within an expander.These pressure drops depend on the gas flow rate and upon the area and configuration of the inlet and exhaust valves.
- Losses due to incomplete expansion
  - The valve controlling the fluid flow may be opened at points during the piston stroke before or after the extreme positions of the piston.For an expander,early cutoff is sometimes advantageous because a relatively small amount of work is produced by the final 10 percent of the piston stroke,whereas friction and heat transfer losses are highest in this region.By shortening the cutoff, the friction losses are reduced at the expense of the small amount of work output at the end of the stroke.
- Heat transfer losses
  - For expanders,heat transfer to the working fluid reduces the enthalpy drop of the fluid during expansion,thereby reducing the output by an amount equal to the heat transfer
- Piston Friction Losses
  - It represents energy that is dissipated as an increase in internal energy of the piston and cylinder and is eventually returned to the working fluid as heat.It is difficult to predict.

LOSSES IN GAS LIQUEFACTION SYSTEMS

(NOT IN SYLLABUS,BUT ONCE ASKED IN KTU UNIVERSITY EXAM)

LOSSES IN **ROTARY** COMPRESSORS AND EXPANDERS

- Inlet valve and outlet valve losses(same as reciprocating)
- Losses due to disk friction
  - The frictional energy dissipation between the rotor and the gas in the space between the rotor and housing represents a loss pf output for an expander or an increased work requirement for a compressor
- Impeller losses
  - It is a function of the blade angles(inlet and exit), the velocity of the fluid at the inlet and at the exit of the blade,and the type of unit(impulse,reaction etc)
- Leaving Losses
  - It represents energy lost as kinetic energy of the outlet stream.