Cryogenic Engineering

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***Abstract*-The three modes namely conduction, convection and radiation are responsible for the heat transfer between the objects. The third mode relates to the heat and cold, we have heat of fire which is infinitely more potent and intense than the heat of the sun as it reaches us or the warmth of animals. But we have no cold save such as is to be got in wintertime, or by application of snow or ice. And therefore all natural condensations caused by cold should be investigated in order that there causes being known. This investigation can be done with the help of cryogenic engineering.**

Cryogenic processing has its US origins at the water town arsenal, during the world war II under the guidance of Clarance Zener, who would go on to develop the zener diode among other advances in solid state physics. Junkers company in germany at the 1930's used the cryogenic processing on the components of their jumo aircraft engines. Junkers engineer suggested that they use the process on the chain saw blade links. They did and start cryo treating their chainsaw blades but it a secret so other manufacturer could not able to make better blades.

The measures important in cryogenic engineering from the application point of view are: (a) basics of cryognics and its recent use. (b) properties of cryogenic fluid, under which T-S diagram of cryogenic fluid. (c) properties of materials at cryogenic temperature. (d) cryocoolers such as stirling coolers and giffen macmahon coolers. (e)cryogenic insulations against the third mode of heat transfer i.e. radiation.

***Keywords*-boiling point, coolers, properties, T-S diagram.**

I. INTRODUCTION

What is Cryogenics?
-Kryo –Very cold (frost)
Genics –to produce
Cryogenics is the science and technology associated with generation of low temperature below 123 K.

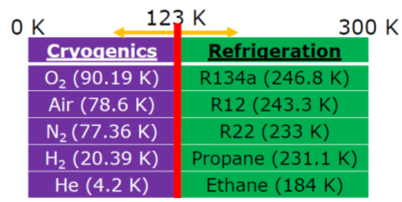

Fig 1. The comparison between refrigeration and cryogenics

Table 1
Fluids having boiling point less than 123k.

Cryogen	**Boiling Point (K)**	**Triple Point (K)**
Methane, CH4	111.67	90.69
Oxygen, O2	90.19	54.36
Argon, Ar	87.30	83.81
Air(N2+O2+Ar)	78.6	59.75

II.APPLICATIONS

A)Space

a) Rocket propulsion
b) Cooling of infrared sensors
c) Space simulation

a)Rocket propulsion

- Cryogenic engines are powered by cryogenic propellants.
- Liquid Hydrogen is used as a fuel to propel the rocket.
- Liquid Oxygen is used as an oxidizer.

b)Cooling Of Infrared Sensors

- Cooling of IR detectors, Telescopes, Cold probes, etc. are some of the major applications of cryogenics.
- Development of miniature and small cryocoolers for satellites for an improved accuracy and reliability of earth observation.

c)Space Simulation

- Space simulations chambers are realistic environment for space craft. The cold space is simulated at cryogenic temperatures by use of LN2.

- The levels of vacuum required in space simulation chambers are vey high.
- This is achieved by the use of cryo pumps and turbo molecular pumps

B) Mechanical

a) Magnetic separation
b) Heat treatment
c) Recycling

a)Magnetic separation

- Magnetic separation technique used in variety of applications enhancing the brightness of kaolin, improving the quality of ultra high purity quartz etc.

b) Heat treatment

- The lives of the tools, die castings & their dies, forgings, jigs & fixtures etc increase when subjected to cryogenic heat treatment.

C) Medicine

a) Cryosurgery
b) Cell preservation
c) Food preservation

a)Cryosurgery

- Cryosurgery is the novel technique in which the harmful tissues are destroyed by freezing to cryogenic temperature.
- Cryosurgery has shorter hospital stay, less blood loss, and small recovery time.
- It is generally used in patients with localized prostate and kidney cancer, skin disorders, retinal problems, etc.

b)Cell preservation

- Systems are developed to preserve blood cells, plasma cells, human organs and animal organs at cryogenic temperatures.

c)Food preservation

- Preserving food at low temperature is a well known technique.
- Cooling of sea foods, meat (sea export), milk products for long time preservation is achieved by use of LN2.

III.PROPERTIES OF CRYOGENIC FLUIDS

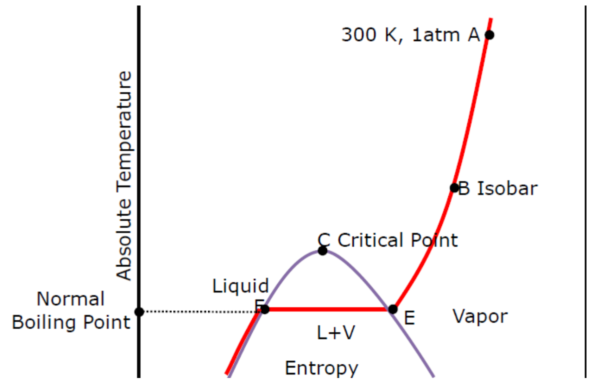

Fig .2 T-S diagram of cryogen

Table 2.Properties of Some Cryogens

Sat. Liq. at 1atm		LHe 4	LH_2	LN_2	LAir	LOX
Normal Boiling Point	K	4.214	20.27	77.36	78.8	90.18
Critical Pressure	Mpa	0.229	1.315	3.39	3.92	5.08
Density	kg/m³	124.8	70.79	807.3	874	1141
Latent Heat	kJ/kg	20.90	443	199.3	205	213

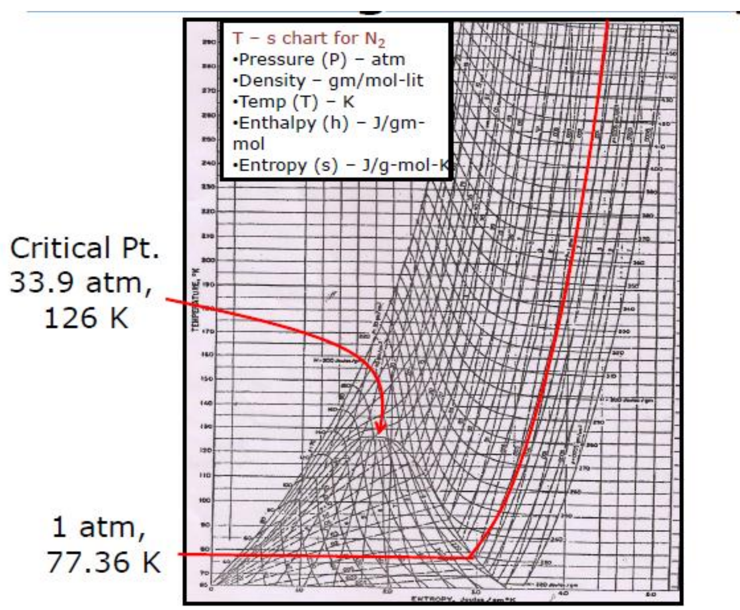

Fig 3. T-S diagram of nitrogn

A) Cryogenic Fluids

a)Liquid methane

- It boils at 111.7k

- It can be used as rocket fuel
- In the form of compressed natural gas.

b)Liquid nitrogen (LN2)

- Nitrogen is primarily used to provide an inert atmosphere in chemical and metallurgical industries
- It is also used as the liquid to provide refrigeration
- Food preservation, Blood, cell preservation

c)Liquid oxygen (LOX)

-It is largely used in iron and steel manufacturing company.

IV. PROPERTIES OF MATERIALS AT CRYOGENIC TEMPERATURE:

A) Mechanical properties:

Properties of materials change, when cooled to cryogenic temperatures.

-For example:

- Rubber when quenched in LN2, it turns hard and breaks like a brittle material .
- Wires made of materials like Nb –Ti, exhibit zero resistance when subjected to LHe temperatures (Superconductivity).

The above examples show that material becomes hard and brittle at low temperature.

The electrical resistance decreases as temperature decreases.

Hence, a knowledge of behavior and properties like strength, ductility, thermal and electrical conductivities etc. of materials is necessary for the proper design.

Table 3. Mechanical properties:

Sr. No.	Property
1	Yield and Ultimate Strengths
2	Fatigue Strength
3	Impact Strength
4	Hardness and Ductility
5	Elastic Moduli

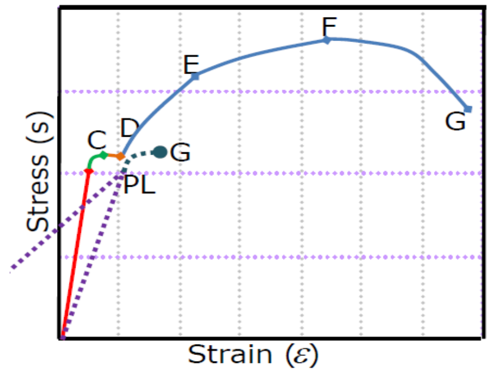

Fig . 4 Stress-Strain Graph

B) Thermal properties:

- The properties of the material change when cooled to cryogenic temperature.
- The electrical resistance of the conductor decreases as the temperature decreases.
- Shrinkage of metals occurs when cooled to lower temperature.
- Systems cools down faster at low temperature due to decrease in specific heat.
- Hence study of properties of materials at low temperatures is necessary for proper design.

Table 4. Material Properties

Sr. No.	Thermal Properties
1	Thermal Expansion/Contraction
2	Specific Heat of Solids
3	Thermal Conductivity

V. CRYOCOOLERS

A **Cryocooler** is a standalone cooler, usually of table-top size. It is used to cool some particular application to cryogenic temperatures.

SOME OF THE CRYOCOOLERS ARE:

- STIRLING REFRIGERATOR
- GIFFEN MACMAHON COOLER

A)STIRLING REFRIGERATOR

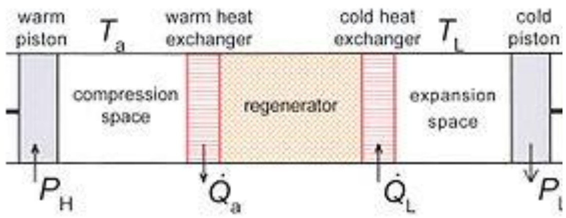

Fig. 5 Schematic Diagram of a Stirling Cooler.

The system has one piston at ambient temperature T_a and one piston at low temperature T_L.The basic type of Stirling-type cooler is depicted in Fig.1. From left to right it consists of a piston, a compression space, and heat exchanger (all at ambient temperature T_a), a regenerator, and a heat exchanger, expansion space, and a piston (all at the low temperature T_L). Left and right the thermal contact with the surroundings at the temperatures T_a and T_L is supposed to be perfect so that the compression and expansion are isothermal. The work, performed during the expansion, is used to reduce the total input power. Usually helium is the working fluid.

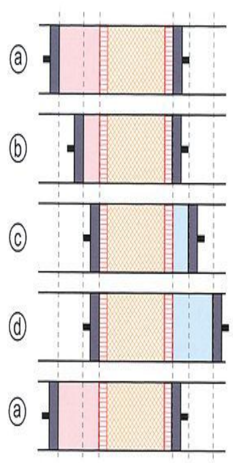

Fig . 6 Stirling Cycle Process

B) GIFFEN MACMAHON COOLER-

- Gifford-McMahon (GM) cooler have found widespread application in many low-temperature systems e.g. in MRI and cryopumps.
- Helium at pressures in the 10 to 30 bar range is the working fluid. The cold head contains a compression and expansion space, a regenerator, and a displacer.
- Usually the regenerator and the displacer are combined in one body. The pressure variations in the cold head are obtained by connecting it periodically to the high- and low-pressure sides of a compressor by a rotating valve.
- Its position is synchronized with the motion of the displacer. During the opening and closing of the valves irreversible processes take place, so GM-coolers have intrinsic losses.
- This is a clear disadvantage of this type of cooler. The advantage is that the cycle frequencies of the compressor and the displacer are uncoupled so that the compressor can run at power-line frequency (50 or 60 Hz) while the cycle of the cold head is 1 Hz.
- In this way the swept volume of the compressor can be 50(60) times smaller than of the cooler.

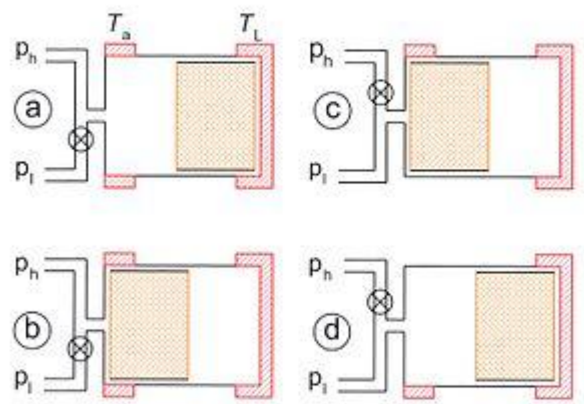

Fig. 7 The four stages in the cooling cycle of the GM cooler.

The cycle starts with the low-pressure (lp) valve closed, the high-pressure (hp) valve open, and the displacer all the way to the right (so in the cold region). All the gas is at room temperature.

- From a to b. The displacer moves to the left while the cold head is connected to the hp side of the compressor. The gas passes the regenerator entering the regenerator at ambient temperature T_a and leaving it with temperature T_L. Heat is released by the gas to the regenerator material.
- From b to c. The hp valve is closed and the lp valve opened with fixed position of the displacer. Part of the gas flows through the regenerator to the lp side of the compressor. The gas expands. The expansion is isothermal so heat is taken up from the application. This is where the useful cooling power is produced.
- From c to d. The displacer moves to the right with the cold head connected to the lp side of the compressor forcing the cold gas to pass the

regenerator, while taking up heat from the regenerator.

- From d to a. The lp valve is closed and the hp valve opened with fixed position of the displacer. The gas, now in the hot end of the cold head, is compressed and heat is released to the surroundings. In the end of this step we are back in position a.

VI. CRYOGENIC INSULATION

- Vessels that require a high level of thermal isolation are typically enclosed in an outer vessel with a separating space that is vacuum evacuated.
- With an ambient vacuum 24-hour settle pressure in the 10^{-4} torr range, convective heat transfer across this space is virtually eliminated.
- Creating a very small heat path from the outer to the inner vessel typically controls conductive heat transfer.
- Selecting a material for this heat path that has very low thermal conductivity properties normally works well.
- Such materials include G-10 NEMA Grade Fiberglass and/or low-density ceramics. Radiated heat transfer is typically controlled by the barrier placed around the inner vessel.
- Its mission is to prevent heat from radiating into the inner vessel.
- One common radiation barrier used in cryogenic applications is known as **Multilayer Insulation (MLI), or Super insulation**

Multilayer Insulation (MLI):

- The space program encouraged the development of MLI around 1960. The MLI generally contains multiple layers of reflective material separated by spacers having low conductivity.
- MLI consists of many radiation shields stacked in parallel as close as possible without touching one another.
- MLI will typically contain about 60 layers per inch. MLI is anisotropic by nature, making it difficult to apply to complex geometries.
- MLI is generally very sensitive to mechanical compression and edge effects, requiring careful attention to details during all phases of its installation. Accordingly, performance in practice is not typically as good as the theoretically possible.
- Each layer is isolated from the other by spacer material such as polyester, nylon, or Mylar.
- The aluminum foil is carefully wrapped around the container such that it covers the entire surface of the inner vessel.
- Spacer material, as described, is placed between the layers to completely prevent the separate coverings of foil from contacting. Should they touch, a thermal short circuit will occur and increase the heat transfer.
- The layers can be applied manually as blankets. These are hand cut to fit and wrapped over the vessel and vessel ends.
- Tape that has low out-gassing properties is then used to hold the blanket layers in place. Another method of applying the layers is by "orbital wrapping". This method is used where high-volume vessels are being manufactured.
- Special equipment is required that wraps the alternating layers much like the wrapping of a spool of string.
- As the number of layers increase the insulation capability is also increased. Typically layers adding up to about one inch in total thickness is applied in the liquid nitrogen temperature.

- MLI is designed to work under high order vacuum, i.e., pressure below about 1 X 10^{-4} torr.
- To obtain this vacuum generally requires lengthy pumping along with heating and purging cycles.
- Chemical gettering materials are required to absorb the out-gassed molecules to maintain the vacuum over extended periods.
- Super insulation advancements are being made at the Kennedy Space Center. A new-layered cryogenic insulation system is being developed.
- This insulation is different from others due to its superior thermal performance in "soft" vacuum conditions. This system overcomes some of the typical shortcomings of super insulation discussed above.
- Those shortcomings include exhibition of different insulation properties when measured in different directions and sensitivity to mechanical compression.

VII. CONCLUSION

The properties of materials changes when cooled to cryogenic temperature. Stainless steel is the best material from the cryogenic point of view. Carbon steel cannot used at low temperature as it undergoes ductile to brittle transition. Ultimate or yield strength of any material increases at low temperature while the ductile and impact strength decreases at low temperature. The coefficient of thermal expansion decreases with decrease in temperature. For pure metals, kt is constant above LN2 temperature. For impure metal kt decreases with decrease in temperature. Electrical conductivity of metallic conductor increases with low temperature.

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