Review on Design of Low Heat Leak Liquid Helium Dewar

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Abstract— IPR is planning to develop an indigenous Liquid Helium Refrigeration/Liquefaction Plant. So, at the end of the Liquefaction process when the Liquid Helium is Produced, it is required to store. And from that it is used for different application and the generated He vapor is resupplied to the plant for the further liquefaction. So, to store this produced liquid helium, Liquid Helium Dewar will be used. The proposed Liquid helium (LHe) Dewar is to store liquid helium of 1000 liters. This LHe storage Dewar should be designed such that the heat leak will as minimum as possible. To reduce heat leaks, it is planned to use vacuum and multilayer insulations (MLI). The vacuum space between inner and outer shell should have vacuum of 10-5 mbar or lower. The support structures of the inner shell which will carry the LHe need to be done considering the mechanical stress and low heat leaks. Appropriate ports should be included for vacuum pumping, safety valve and burst disc connection for pressure release, LHe and vapor process line connections, instrumentation connections. Requirements of these equipments also have to be worked out to find overall specs for procurement. The Dewar can be of vertical configuration having cylindrical shell with top and bottom dish ends.

Key words: Liquid Helium Dewar, MLI

I. INTRODUCTION

IPR is planning to design an indigenous Liquid Helium Plant which is used for production of liquid helium. During designing of the helium liquefaction systems, the system constraints have to be properly designated and optimized (like mass flow rates, component efficiencies, purity of gas, temperature levels of components, pressures etc.), so that maximum liquid production is to be attained with minimum power input. A helium liquefier has to bring down the temperature of feed gas from normal room temperature to 4.2 K and this requires many steps of refrigeration or cooling components.

The thermal cycle for liquid helium production for which the LHe Dewar will be designed is shown in fig.1.

In the proposed design of the HRL Plant at IPR, it will operate on either refrigeration or liquefaction or both. So, at the end of the process, when the helium will liquefied, it is required to store and from that it will be used for different application and the generated He vapour is resupplied to the plant for the liquefaction. So, to store this produced liquid helium, Liquid Helium Dewar will be used. This LHe storage Dewar should be designed such that the heat leak will as minimum as possible because as the heat leak in the Dewar increases the boil off rate of Liquid Helium is also increases. And the Dewar should have the capacity of about 1000 liters. And it should have Heat In leak less than 20 W.

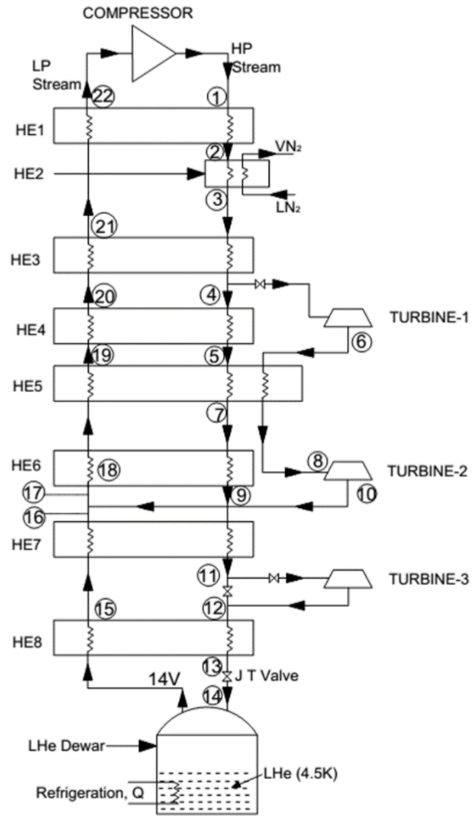

Fig. 1: Thermal cycle of HRL Plant (Courtesy: IPR)

II. DEWAR

DEWAR is a double walled container with the space between two vessels filled with an insulation and gas evacuated from space.

A. *Parts of Dewar [1]:*

DEWAR mainly contains inner vessel, outer vessel, inner and outer stiffening rings, insulations, piping, suspension system etc.

1) *Inner Vessel*

Inner vessel is inner most part of the storage vessel. It is surrounded by cryogenic fluids. It is also called product container.

2) *Outer Vessel*

Outer vessel is used for covering the inner vessel. It contains the high vacuum necessary for the effectiveness of the insulation and acts as a vapour barrior for the insulations.

- Stiffening Rings: Stiffening rings are used to support the weight of inner vessel and cryogenic fluid. Also it is used to hold the outer vessel shell circular.

3) *Insulation*

The space between inner vessel and outer vessel is filled with insulation. It is used to prevent the heat in leak from ambient temperature to cryogenic temperature.

4) Suspension System

The suspension system must be used to support the inner vessel with in the outer vessel.

5) Piping

Piping is necessary to filled and remove the liquid from the vessel and to vent vapour from the vessel.

6) Safety Devices

Safety devices are used to relieve the overpressure so that damage to the inner vessel is avoided.

B. Selection of Shape of Dewar

According to Ken Harrison [2], Deflection is the important factor for shape selection of the Dewar. The best shape to minimize both material and deflection is a sphere. . But the limitation to this shape is that some applications do not readily fit in it. The forming costs of the hemispheric halves can also be expensive for larger chambers So, The next best shape is a cylinder with length is equal to diameter. This is one of the most common shapes, and the rigidity is almost as good as a sphere. Because in this type of shape surface area is only 10% more than the sphere of same storage capacity.

According to Saurabh Lawate, B. B. Deshmukh [3], The Surface Area of Torispherical heads is less than the surface area of elliptical heads & hemispherical head. For Pressure (P<10bar), Deformations in elliptical & Torispherical dish ends are in close agreement And The forming cost of Torispherical heads is less than elliptical heads & hemispherical heads because of availability regular circular curves on the edges then a larger curve as it heads.So, For Pressure (P<10 bar), Torispherical shape is economical.

So, The Selected Shape of Dewar is Cylindrical with top and Bottom Torispherical head.

C. Selection of Material

According to George Behrens, William Campbell in "design guidelines for cryogenic systems"[4] For the Cryogenic application SS-304 L is widely used because it does not oxidize and can be heated to very high temperatures for bake-out to reduce the component of the gas load caused by diffusion (gases within the crystalline structure of the metal). Another reason for using S/S-304L is that it is easily electro polished, which provides a clean surface free of oxidation and contamination. Stainless steel is also easily welded with the (TIG) Tungsten Inert Gas (argon) method that is needed for producing vacuum tight welds for high and ultra-high vacuum operation.

According to Ken Harrison [2], To obtain a good leak proof chamber, the weldability of the material must be excellent. So, for any vacuum application, Stainless steel should be used because it has good weldability property.

According to C Gayari [5], Austenitic stainless steels of the I8/8 types (18% chrome, 8% nickel) offer a favorable set of properties which make them particularly well suited for the use of in the vacuum and cryogenic application because it has good welding properties , low effect of sensitization ,good mechanical properties.

According to Phil Danielson [6], choose that material for vacuum system design which has low outgassing rate. And the surface of the l8/8 type stainless steels is inert, passive and has a very low outgassing rate i.e. 6 x 10^{-9}(torr liter/sec/cm^2)

So, SS -304 L is selected for the inner vessel and Carbon steel SA-516 grade 60 is selected for outer vessel because it not subjected to cryogenic temperature.

D. Selection of Insulation

There are different types of insulations are used in the cryogenic application for reducing the heat in leak and from that we have to choose proper insulation for our application.

According to Holger Neumann [7], Multilayer Insulation is most effective for Low Temperature Application because It has low heat conductivity at low Temperature Range as shown in fig 2.

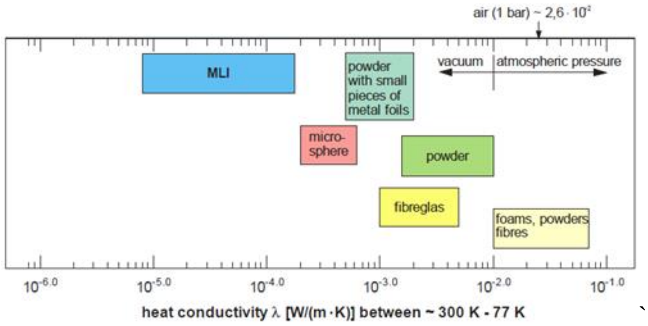

Fig. 2: Range of heat conductivity of various insulation materials at different temperature. [7]

MLI consists of layers of alternate low emittance radiation shields separated either by low conductivity spacer or by crinkling or embossing the shields so that when placed against each other, the shields only touch at a few discrete points.

1) Selection of Shield Material of Multilayer Insulation

According to Jacobus Henry Hodgman [8], a highly polished Aluminum film is most commonly used as shield material because it has very low emissivity i.e. 0.02.

So, aluminum film is selected for the shield material of multilayer insulation.

2) Selection of Spacer Material of Multilayer Insulation

According to Jacobus Henry Hodgman [8], if polymer net is used in place of composite paper there is further reduction of heat transfer because the contact area through which heat is transferred from one shield to another is reduced and Nylon is most commonly used as spacer material because it has low thermal conductivity value.

So, nylon net is selected for the spacer material of the multilayer insulation.

E. Selection of Vacuum Level

In liquid Helium Dewar we need to have least amount of heat load coming into the cryogen reservoir (at 4.5K). The maximum amount of heat load that can be transferred into the cryogen reservoir is due to natural convection from atmospheric condition (at 300K), hence to reduce this heat load we have to evacuate the space between vacuum jacket and cryogen reservoir.

The space is evacuated using pumping station to create vacuum in the range of>10^{-5} mbar. The pumping station consists of Turbomoleculer pump backed by a rotary or scroll pumps. This arrangement of pumps is enough to produce high vacuum of above 10^{-5} mbar.

III. CONCLUSIONS

The current work deals with the design of low heat leak liquid helium Dewar. In context to the design requirements it can be concluded that from the review that the cylindrical shape with torispherical head is the most appropriate shape for our Dewar and SS – 304 L is most suitable as a material of inner vessel and Carbon steel SA – 516 grade 60 is most suitable as a material of outer vessel. And for the reduction of heat in leak multilayer insulation with highly polished aluminum as shield material and nylon net as a spacer material with vacuum below 10^{-5} mbar is used. And for the production of such a vacuum Turbomolecular pump backed by rotary pump is used. And by using this data design of Dewar will be carried out.

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