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Research Paper

Design Aspects Of Cylindrical Cryogeic Storage Vessel

Engineering

KEYWORDS : storage vessel ,Insulation, Collapsing pressure, Inner vessel, Outer vessel, boil-off rate. Pipe and other seftey device.

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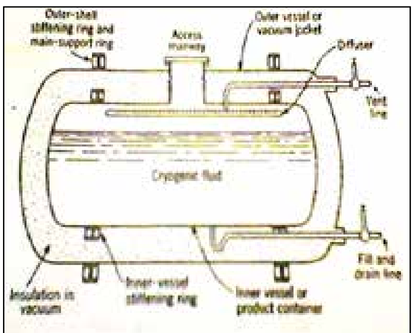
ABSTRACT

This paper represents of the design aspects of cryogenic dewar vessel for liquid nitrogen. Design making process is applicable to entire field of engineering design. Storage vessels are closed containers used to store cryogen at desirable condition of pressure and temperature. Cryogenic storage vessels are pressure vessels are used for storage cryogenic liquids with minimum heat in-leak into the vessel from the outside as far as possible. The challenge of design is to use such materials that do not lose their desirable properties at such a low temperature.

INTRODUCTION

The cryogenic fluid has been liquefied and purified to the desired level; it must then be stored and transported. Cryogenic fluid storage-vessel and transfer line design has progressed rapidly as a result of the growing use of cryogenic liquids in many areas of engineering and science. Storage vessels range in type from low performance containers, insulated by rigid foam or fibrous insulation so that the liquid in the container boils away in a few hours, up to high performance vessels, insulated by multilayer evacuated insulations so that less than 0.1 percent of the vessels content is lost per day



Elements of a dewar vessel.

STORAGE VESSEL

The development of the Dewar vessel represented such an improvement in cryogenic fluid storage vessels that it could be classed as a "break-through" in container design. The high performance storage vessels in use today are based on the concept of the dewar design principle a double walled container with the space between the two vessels filled with an insulation and the evacuated from the space. Improvements have been made in the insulation used between the two walls, but the dewar vessel is steel the starting point for the performance cryogenic fluid vessel design.

The storage vessel consists of an inner vessel called the product container, which encloses the cryogenic fluid to be stored. The inner vessel is enclosed by an outer vessel or vacuum jacket, which contains the high vacuum necessary for the effectiveness of the insulation and serves as a vapor barrier to prevent migration of water vapor.

The space between the two vessels is filled with an insulation, and the gas this space may be evacuated. In small laboratory Dewar's, the "insulation" consists of the silvered walls and high vacuum alone; however, insulations such as powders, fibrous materials, or multilayer insulations are used in larger vessels. Since the performance of the vessel depends to a great extent upon the effectiveness of the insulation.

The design capacity and design pressure for a storage vessel is usually established by the storage requirement of the user. When large storage vessels first came into use, most were custom-tailored for the specific use. Most cryogenic vessel manufacturers have reached the point that a set of standard size vessels is available. These standard units are generally more economical than specially made vessels

Cryogenic fluid storage vessels are not designed to be completely filled for several reasons. First, heat in leak to the product container is always present; there for the vessel pressure would rise quite rapidly because of vaporization of the liquid if no vapor space were allowed. Second inadequate cool-down of the inner vessel during a rapid filling operation would result in additional boil-off, and the liquid would be percolated through the vent tube if no ullage space were provided. cryogenic-fluid storage vessels may be constructed in almost any shapes one desire- cylindrical, spherical, conical, or combination of these shapes generally ,one of the most economical configuration is the cylindrical vessel with either dished, elliptical, or end

closures. A cylindrical vessel with a length –to diameter ratio of unity has only 21 percent greater surface area than a sphere of the same volume, so the heat in-leak penalty is not excessive for cylindrical vessel compared with a spherical vessel .Cylindrical vessels are usually require for transportable trailers and railway *cars because the outside diameter of the vessel cannot exceed about* 2.44m(8ft) for normal highway transportation. no industrial plant without pressure vessels, steam boilers, tanks, autoclaves, collectors, heat exchangers, pipes, etc. More specifically, pressure vessels represent fundamental components in sectors of paramount industrial importance, such as the nuclear, oil, petrochemical, and chemical sectors.

MECHANICAL DESIGN METHOD FOR THE CRYOGENIC STORAGE VESSEL

The detailed conventional-cryogenic-fluid storage vessel design is covered in such standards as the American society of mechanical engineers (ASME) boiler and pressure vessel code, section VIII (1983), and British Standards Institution standards 1500 or 1515. Most users require that the vessels be designed, fabricated, and tested according to the code for sizes larger than about 250 dm^3 i.e 66 U.S. gallons, because of the proven safety code design.

1.1 INNER VESSEL DESIGN

The Product container must withstand the design internal pressure, the weight of the fluid within the vessel, and bursting. There is no beam bending in vertical vessel. The inner vessel must be constructed of a material compatible with the cryogenic fluid. Therefore stainless steel, aluminum, monel, and in some cases copper are commonly used for the inner shell. These materials are much more expensive than ordinary carbon steel. So the designer would like to make the inner vessel wall as thin as practical in order to hold the cost reasonable without sacrificing the strength. In addition, a thick-walled vessel requires a longer time to cool down. Wastes more liquid in cool down. Wastes more liquid in cool-down, and introduces the possibility of thermal stresses in the vessel wall during cool-down. For these reasons, the inner vessel is designed to withstand only the internal pressure and bursting forces, and stiffening rings are

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used to avoid bursting .According to the ASME code, section VIII the minimum thickness of the inner shell for a cylindrical vessel should be determined from

$$t=\frac{pD}{2s_a e_w-1.2p}=\frac{pD_o}{2s_a e_w+0.8p}\ldots\ldots\ldots\ldots(1.1)$$

Where,

p=design internal pressure (absolute pressure for vacuum jacketed vessels)

D=inside diameter of the shell

D_0=outside diameter of the shell

S_a=allowable stress (approximately one-fourth minimum ultimate strength of material)

e_w =weld efficiency

Values of allowable stress for some materials used in cryogenic vessel construction are given in table(1.1),and values for weld efficiency are given in table (1.2).

The minimum thickness for spherical shells, hemispherical heads, elliptical head or ASME torispherical head is determined from

$$t_h=\frac{pDK}{2s_a e_w-0.2p}$$

$$t_h=\frac{pD_oK}{2s_a e_w-2p(K-0.1)}$$

where D is the inside diameter of the spherical vessel or hemispherical head, of the inside major diameter for an elliptical head ,or 2(crown radius) for the ASME torispherical head. The value of the constant K is givan by

K=1/6

Where is the minor diameter of the elliptical head. For the ASME torisperical head, K=0.885.

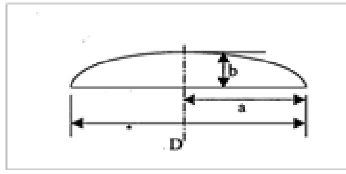
TABLE-1.1
ALLOWABLE STRESS FOR MATERIALS AT ROOM TEMPERATURE OF LOWER (ASME CODE,SECTION VIII,1983)l

Material		Allowable Stress MPa
Carbon steel(for outer shell only	SA-285 Grade C SA-442 Grade 55 SA-299 SA-516 Grade 60	94.8 94.8 129.2 103.4
Low alloy steel	SA-202 Grade B SA-353-B(9%Ni) SA-203 Grade-E SA-410	146.5 163.7 120.6 103.4
Stainless steel	SA-240(304) SA- 240(304L) SA-240(316) SA-240(410)	129.2 120.6 129.2 112.0
Aluminum	SB-209(1100-0) SB-209(5083-0) SB-209(6061-T4) SB-209(3004-0)	16.2 68.9 41.4 37.9
Copper	SB-11 SB- 169(annealed)	46.2 86.2

The inner-shell stiffening rings be sized by using the fact that they must support the weight of the fluid within the inner shell,

TABLE-1.2
WELD EFFICIENCIES FOR ARC-WELDED AND GAS WELDED JOINTS (ASME CODE, SECTION VIII, 1983)

Types of joint	Fully Radio gra phed	Spot Examined	Not Spot Examined
But joints with complete penetration	1.00	0.85	0.70
Single welded butt joint, no backing strip	0.90	0.80	0.65
Single welded butt joint, no backing strip	-	-	0.60
Double full fillet lap joint	-	-	0.55



Volume Of Head Fig-1.1 (a)

VOLUME OF ELLIPTICAL HEAD
Vh= (from the table (3.3)for head volume) Where Vh-Volume of elliptical head.

TABLE-1.3
GEOMETRIC CHARACTERISTICS OF HEADS
D=Inside Diameter, =Outside Diameter,=Thickness, R=Dish RADIUS (ASME TORISPHERICAL)

D-Inside diameter of the vessel

Total volume=cylindrical volume+2(head volume)

v =+2

a= ,b= ,L=D

HEMISPERIC-AL	2:1 ELLIPTICAL	ASME TORISPHRICAL
Internal volume $V=\pi D^3/12$	$V=\pi D^3/24$	$V=\frac{\pi R^3}{39.173}$
Material volume $V_h=1/2\pi(D+t_h)^2t_h$	$V_h=0.345\pi(D+t_h)^2t_h$	$V_h=0.345\pi(D+t_h)^2t_h$
Outside surface area $A_0=1/2\pi D_0^2$	$A_0=0.345\pi D_0^2$	$A_0=0.264\pi R^2$

OUTER VESSEL DESIGN

$$P_C=\frac{2E\left(\frac{t}{D_{00}}\right)^3}{1-v^2}\ldots\ldots\ldots\ldots\ldots(1.4)$$

Where critical pressure
E=young's modulus of shell material
t=shell thickness

outside diameter of shell
V=Poisson's ratio for shell material.
Values for young's modulus and poisson's ratio for materials are given in table 1.5

A "long" cylinder is defined as one for which the length-to-diameter ratio meets the following Condition,

$$\frac{L}{D_{00}}>1.140(1-v^2)^{1/4}\left[\frac{D_{00}}{t}\right]^{1/2}\ldots(1.5)$$

Where L is the unsupported length of the cylinder (distance between stiffening rings. For the outer shell). Of course this applies to horizontal cylinders.

$$P_c = \frac{2.42E\left(\frac{t}{D_{oo}}\right)^{5/2}}{(1-\nu^2)^{3/4}\left\{\left(\frac{L}{D_{oo}}\right)-0.45\left(\frac{t}{D_{oo}}\right)^{1/2}\right\}} \ldots\ldots\ldots(1.6)$$

Where

E=Young modulus of elasticity

t=thickness of outer vessel

=dia of outer vessel

The heads for the outer vessel must withstand the collapsing load of atmospheric pressure, and the mode of failure is elastic instability rather than rupture due to excessive stress. The critical pressure for a hemispherical, elliptical or torisperical head (or for a spherical vessel) is given by

$$p_c = \frac{0.5E\left(\frac{t_h}{R_0}\right)^2}{3(1-\nu^2)^{1/2}} \ldots\ldots\ldots\ldots\ldots\ldots(1.7)$$

Hence, =critical pressure p_c

E=Young modulus of elasticity

t_h=thickness of outer vessel head

v=poisson's ratio of the shell

material

R_o =outside radius of the spherical head or spherical vessel, the equivalent radius for the elliptical head, or the crown radius for the torispherical head. The equivalent radius for elliptical heads is given by =D, where D is the major dia and is the factor given is table-(1.6)

The collapsing or critical pressure is given by the following expression ,according to the ASME code:

$$P_c = 4p_a \ldots\ldots\ldots\ldots\ldots(1.8)$$

The factor 4 is required for safety, and is the allowable external pressure (atmospheric pressure for the outer shell or head of a dewar vessel).

INSULATION USED IN STORAGE VESSELS

Many cryogenic applications require perfection of insulation. In relatively large scale equipment the heat flow must be kept very small to conserve refrigeration or to preserve liquids having small heats of vapourization. Temperature to ineer vessel at cryogenic temperature .Since the production of cryogenic liquid is very expensive,its storage should be very effective and economical. An increasing use of cryogenic liquid in research laboratories and industries has necessitated the development of high performance insulated storage vessel for cryogenic liquid. Thus in order to choose the most effective and economical insulation for a particular application, it requires a detail knowledge of various types of insulation for the cryogenic temperature range.

Boil- Off Rate Calculation

Boil-off rate is calculated to judge performance of storage vessel.It shows the effectiveness of insulation along with its economic aspects.

boil off per day =Q_T/E_t100……..(1.9)

Where,= total heat inleak to the vessel during one day E_t = total heat energy required to evaporate all the quantity Now, E_t is determined as under

$E_t = \rho_f$ x h_{fg} x V ……. (1.10)

Where, =density of liquid

=latent heat of evaporation

V= volume of liquid

Now, total heat inleak is made of three components, and is determined by,

$Q_T = Q_1+Q_2+Q_3$………(3.11)

Where Q_1 =Heat inleak through insulation

Q_2 =Heat inleak through suspention system

Q_3=Heat inleak through piping method to find out heat inleak is given under

Piping (and other attachment including safety devices)

The design of piping for fill, drain and vent lines should be carefully done since this can be a serious source of heat inleak.

Piping necessary to remove liquid from the container, vent vapor from the vessel, and so on, introduces a source of heat inleak to the product container. With a properly designed piping system, the heat transfer down the piping is due to conduction along the pipe wall only.[1] In this paper Radiation and conduction heat transfer in stacked radiation shields to be used in the VIP (vacuum insulationpanel) is investigated. Test radiation shields are multi-layered films of 32 nm Al, 12 lmPET and 32 nm Al thicknesses, folded with regular span and stacked in staggered manner. Radius of curvature of the folded parts is measured by a three-dimensional scanner and the contact radius is calculated using Hertz contact theory. Depth wise conduction around the contact spot and two-dimensional radial conduction models are adopted for the theoretical and the numerical analyses, together with measured surface emissivity.[2] Measurement of the effective thermal conductivity of radiation shields is conducted using a vacuum guarded hot plate apparatus. Measurements show very low values between 0.3 and 1.0 MW/m K. Theoretical and numerical results agree with measurements with maximum relative error of 29.1% and 18.3%, respectively. . A simplified conduction model is also proposed and shown to be very useful for practical applications. We find that the stacked radiation shields have very high insulation performance, the numerical model is fairly reliable and finally, conduction is negligibly small compared with radiation for this shield. [3] This paper described about the Spray-on foam insulation (SOFI) has been developed for use on the cryogenic tanks of space launch vehicles beginning in the 1960s with the Apollo program. The use of SOFI was further developed for the Space Shuttle program. The External Tank (ET) of the Space Shuttle, consisting of a forward liquid oxygen tank in line with an aft liquid hydrogen tank, requires thermal insulation over its outer surface to prevent ice formation and avoid in-flight damage to the ceramic tile thermal protection system on the adjacent Orbiter. The insulation also provides system control and stability throughout the lengthy process of cool down, loading, and replenishing the tank[4]

For this reason,the piping runs should be made as long as possible, and thin walled pipe should be used. The thermal contraction of the piping runs must be considered in the piping system design also.

The minimum wall wall thickness for piping subjected to internal pressure is determined according to the ASA Code for Pressure by the following expression:

$t = (pD_o)/(2s_a+0.8p)$…………..(1.12)

Where p = design pressure

D_o =outside diameter of pipe

S_a =allowable stress of pipe material

For piping subjected to external pressure.

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