iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 2 **Issue:** Issue- III **Month of publication:** November 2014

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Design and thermal analysis of cryogenic Fluid storage vessel

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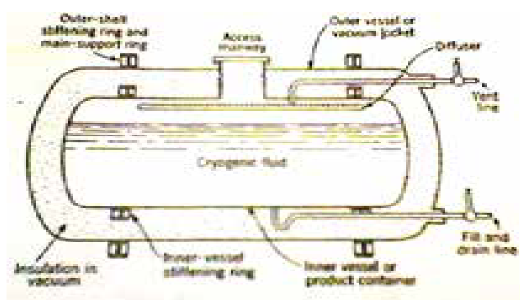
Abstract: This paper represents the design aspects of cryogenic Dewar vessel for liquid nitrogen. Design making process is applicable to entire field of engineering design. Storage vessels are closed containers used to store cryogen at desirable condition of pressure and temperature. Cryogenic storage 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. Thermal Analysis is to be made to the cryogenic fluid storage vessel by using liquid nitrogen and also incorporating FEM analysis. The results are to be tabulate and various graphs are to be plot by the FEM analysis. Finite Element Model (FEM) is the only versatile approach for thermal analysis. The project aims to determine the vaporization of cryogenic liquid (liquid-Nitrogen) for various combinations of inner, outer and insulated materials. 3-D Modeling of storage vessel is done by using Pro-E 2001 software and analysis is made in 2-D modeling by using ansys software. By incorporating the FEM analysis of cryogenic fluid storage vessel of liquid nitrogen the graphs are plot i.e., temperature distribution, temperature gradient, thermal flux and heat flow, which is used for transportation of liquid nitrogen by the vessel.
Key words: Cryogenic fluid, Storage vessel, inner vessel, insulation, outer vessel.

I. 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.

A. Storage vessel

The development of Dewar vessel represents 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 the space between the two vessels filled with an insulation and container with 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 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.

II. 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 cube i.e. 66 U.S. gallons, because of the proven safety code design.

A. Inner Vessel Design

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 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

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

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

$$t_h=\frac{pDK}{2s_a e_w-0.2p}$$
$$t_h=\frac{pD_oK}{2s_a e_w-2p(K-0.1)}$$
……….(1.2) and (1.3) respectively

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 given by

Special Issue-3, November 2014
ISSN: 2321-9653

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

K=1/6
Where is the minor diameter of the elliptical head. For the ASME torisperical head, K=0.885.

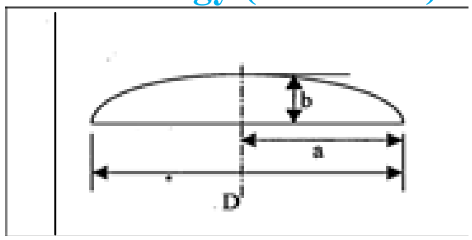
TABLE-1.1
ALLOWABLE STRESS FOR MATERIALS AT ROOM TEMPERATURE OF LOWER (ASME CODE, SECTION VIII, 1983)

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

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

Types of joint	Fully Radio graphed	Spot Examined	Not Spot Examined
Butt 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

Special Issue-3, November 2014
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)



Volume Of Head Fig-2.1 (a)

VOLUME OF ELLIPTICAL HEAD

V_h = (from the table (3.3) for head volume) Where V_h -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 $V=\pi D^3/12$	$V=\pi D^3/24$	$V=\frac{\pi R^3}{38.173}$
Material volume $V_h=1/2\pi(D+t_h)^2 t_h$	$V_h = 0.345\pi(D+t_h)^2 t_h$	$V_h = 0.345\pi(D+t_h)^2 t_h$
Outside surface area $A_0=1/2\pi D_0^2$	$A_0 = 0.345\pi D_0^2$	$A_0 = 0.264\pi R^2$

B. Outer Vessel Design

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

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,

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

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

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

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

$$p_c = \frac{0.5E\left(\frac{t_h}{R_0}\right)^2}{3(1-v^2)^{1/2}} \quad \text{.................(1.7)}$$

Hence, =critical pressure
E = Young modulus of elasticity
t_h = thickness of outer vessel head
v = poisson's ratio of the shell material
Ro = 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-(1.3)

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

$$P_c = 4p_a \quad \text{..............(1.8)}$$

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).

C. 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 vaporization. Temperature to inner 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 $=Q_T / E_t$ 100……..(1.9)

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

$E_t = \rho_f \times h_{fg} \times v$....... (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,

$Q_T = Q_1 + Q_2 + Q_3$ ………(1.11)

Where Q_1 =Heat inleak through insulation
Q_2=Heat inleak through suspension 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] The thermal contraction of the piping runs must be considered in the piping system design also. The minimum 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.

III. MODELING PROCEDURE

By using Pro-E software we have first created outer vessel in part modeling, insulations and inner vessel is modeled by the available dimensions. Other mountings on the vessel are modeled and combined in the assembly modeling by following steps as:

A. *Prepare for a part model design by scoping the design parameters of an adjoining part.*

1. Create a new part model by following the required design parameters.
2. Create an assembly by assembling the new part model with existing part models.
3. Create a 2-D drawing of the new part model that includes views, dimensions, and a title block.

For outer vessel, we use carbon steel or copper alloy as materials. And for inner vessels, material compatible with cryogenic fluids is to be used. Therefore stainless steel, aluminum, Monel are used. As these materials are more expensive than ordinary carbon steel, the designer has to make the inner vessel as thin as possible with nickel chromium metal. Compared with the vacuum alone, evacuate powders are superior in insulation. Different views of outer vessel, insulation and inner vessel are shown.

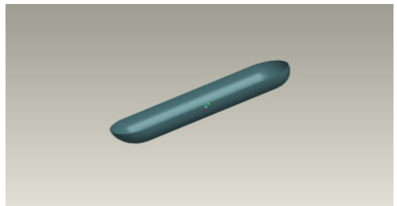


Fig:3.1 Outer Vessel

Fig:3.2 Insulation

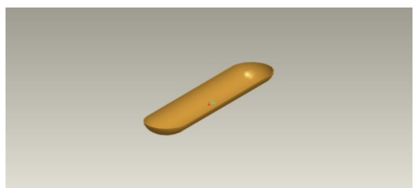


Fig:3.3 Inner Vessel

B. Assembling

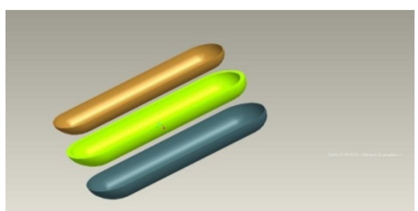


Fig:3.4 Before Assembling

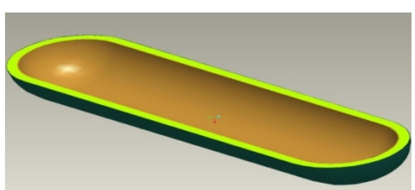


Fig:3.5 After Assembling

IV. RESULTS

A. Thermal Analysis

Before developing the component, the model compulsory has to subject for thermal analysis being able to understand thermal issues prior to the completion of the design. The main aim of the thermal analysis is to obtain the temperature distribution, temperature gradient, and thermal flux, heat flow for various combinations of inner, outer and insulated materials.

For this a typical ANSYS program which may have FEM (Finite Element Model) is used by importing hyper mesh after

Special Issue-3, November 2014
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

applying boundary conditions.

4.2 Performing a Typical Ansys Analysis

It consists of three distinct steps:

a. Build the model.
b. Apply loads and obtain the solution.
c. Review the results.

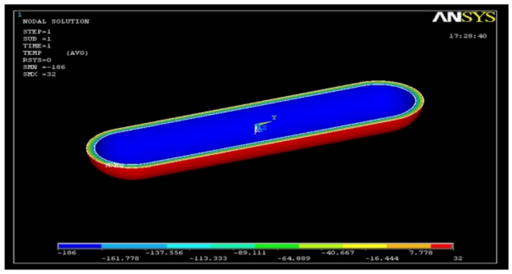


Fig:4.1 Temp Distribution

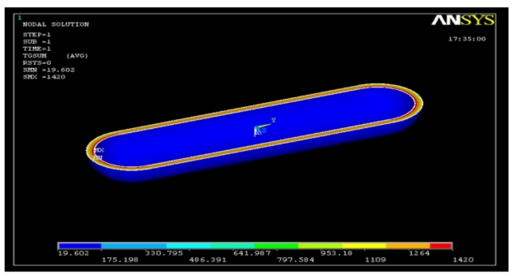


Fig:4.2 Temperature Gradient

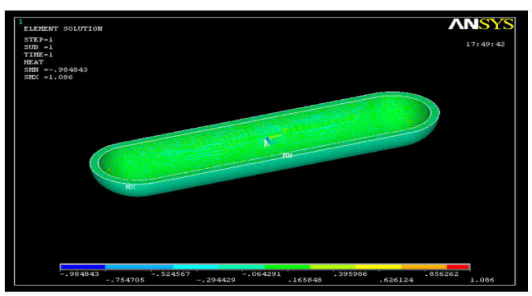


Fig:4.3 Heat flow

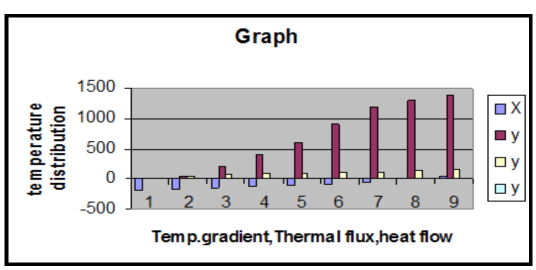


Fig:4.4 The Thermal conductivity of wood is low the temperature of inner surface is low.

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V. CONCLUSION

The design aspects to decrease the vaporization of cryogenic liquid (LN2) for various combination of inner, outer and insulation materials of cryogenic fluid storage vessel for storing liquid nitrogen at a design temperature of -196˚C and at a design pressure of 16 kg/cm^2 are made.

Thermo mechanical analysis is performed, then changes in material property with respect to temperature is obtained and plotted. On the basis of these analysis made on the shell materials and insulators, out different material combinations considered for the cryogenic vessel, Carbon steel for outer shell fiber glass insulator and Ni-Cr as inner material proved to be the best and is recommended for use in cryogenic applications.

REFERENCES

[1] Jongmin Kim, Choonghyo Jang, Tae- Ho Song * School of Mechanical, Aerospace and Systems Engineering, Korea Advanced Institute of Science and Technology, Guseong-dong 373-1,Yuseong-gu, Daejeon, Republic of Korea

[2] J.E. Fesmire a, ⇑, B.E. Coffman a, B.J. Meneghelli b, K.W. Heckle ba Cryogenics Test Laboratory, NASA, Kennedy Space Center, FL, USAb Cryogenics Test Laboratory, ASRC Aerospace,Kennedy Space Centre, F USA

[3] R.L.BARRON, Cryogenic Systems, McGraw-Hill Book Company, inc., New York, 1984.

[4] ALFRED JENSEN, Statics and strength of materials, McGraw-HILL Book Company, INC.LONDON.