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DESIGN AND STATIC THERMAL ANALYSIS OF DIFFERENT PRESSURE VESSEL HEADS AND MATERIALS USING FEM

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Abstract: The pressure vessel is one of a large number of plant components for which stress analyses must be performed. A pressure vessel is a container designed to hold gases or liquids at a pressure substantially different from the ambient pressure. This Project deals with the Finite element analysis of Pressure vessels with different type of heads keeping the same cylindrical volume and thickness. The desired pressure vessel is designed as per ASME standard section VIII, division I for 8 bar pressure and 24 lit volume. Thus some end connections are tested under FEA for the cause of finding stress concentration zone in each type of pressure vessel head under the same volume and sane pressure. The aim of the project is different designs and static and thermal analysis using ansys software of describes, flat head and elliptical head pressure vessel has low stresses distributed as compare to other heads, so for most applications elliptical heads selected. It shows basic structure and the finite element modeling for analyzing the pressure vessels with different type of heads and different materials like Nimonic 80A, SA516 Gr70 also under high stress zones. In this project we are working on approximate stresses that exist in cylindrical pressure vessels supported on two saddles support are calculated under the different type of end connections by using Finite Element tool. Static structural analysis and thermal analysis is done in order to calculate stresses in vessel finally concluded the suitable design and material.

Keyword: *Pressure Vessel, End connections, Stress analysis, steady state thermal.*

I INTRODUCTION

The typical circular-cylindrical high pressure gas cylinders for permanent gases (that do not liquefy at storing pressure, like air, oxygen, nitrogen, hydrogen, argon, helium) have been manufactured by hot forging by pressing and rolling to get a seamless steel vessel. Pressure vessels are containers having a fluid under high pressure, the fluid can be a liquid or gas depending on the application. The pressure is higher than the ambient pressure which makes it dangerous and in some cases fatal. Few examples of pressure vessels Pressure vessels store large amounts of energy; the higher the operating pressure - and the bigger the vessel, the more the energy released which in the event of a rupture will lead to higher extent of damage or disaster or danger. To prevent stress related vessel rupture and catastrophic failure, main factors that contribute extensively to stress development must be identified and ways of how they can be mitigated must be recognized. Head of the vessel is critical zone and an analysis can provide guidelines in selecting proper head. Engineers standards. A pressure vessel is defined as container with internal pressure, higher than atmospheric pressure. The fluid inside the pressure vessel may undergo state of change like in case of boilers. Pressure vessel has combination of high pressure together with high temperature and may be with flammable radioactive material.

Figure 1 Pressure vessel

1.1 FAILURES OF REASONS:

Materials: Improper selection of material; defects in material.

Design: Incorrect design data; inaccurate or• incorrect design methods; inadequate shop testing.

Fabrication: Poor quality control; improper or insufficient fabrication procedures including welding; heat treatment or forming methods.

Service: Change of service condition by the user inexperienced operations or maintenance personnel upset conditions

1.2 COMPONENT OF PRESSURE VESSEL:

1. Shell
2. Head
3. Nozzle
4. Support
5. Lifting attachments

1.3 TYPES OF PRESSURE VESSEL:

Pressure vessels are defined in American Society of Mechanical Engineer section VIII, Div 1 introduction as "Pressure vessels are containers for containment of pressure either external or internal. The pressure may be from an external source, or by application of heat from a direct or indirect source as shown in below figure.Pressure vessels are generally used as a storage vessel, Heat Exchangers, and Process Vessels

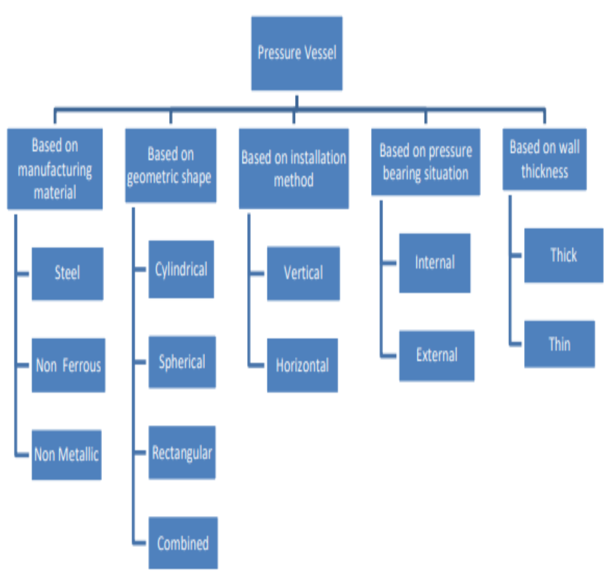


Figure 2 Types of pressure vessel

1.4 ADVANTAGES OF PRESSURE VESSELS:

- It is easier to fabricate.
- They are probably cheaper to construct
- Easily store the pressure
- They pack more efficiently into rectangular structures such as boxes and buildings.

1.5 APPLICATIONS OF PRESSURE VESSELS:

There are numerous applications that require the use of containers for storage or transmission of gasses and fluids under high pressure. Pressure vessels have been used for a long time in various applications in both industry and the private sector. Pressure vessels are probably one of the most widespread equipment within the different industrial sectors. In fact, there is 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 and also in the sectors as industrial compressed air receivers and domestic hot water storage tanks Other examples of pressure vessels are diving cylinders, recompression chambers, distillation towers, pressure reactors, autoclaves, and many other vessels in mining operations, oil refineries and petrochemical plants, nuclear reactor vessels, submarine and space ship habitats, pneumatic reservoirs, hydraulic reservoirs under pressure, rail vehicle airbrake reservoirs, road vehicle airbrake reservoirs, and storage vessels for liquefied gases such as ammonia, chlorine, propane, butane and LPG.

II LITERATURE REVIEW

RELATED WORK In this section research papers are discussed related to the present work. Published papers are highlighted in this section.

In the base paper [1] a cylindrical pressure vessel, as used to generate steam at low pressure for a boiler drum has been taken, the vessel consists of a cylindrical portion with the two ends closed using hemispherical structure. A nozzle is welded on at the midpoint of the length of the vessel which is supported on two supports. The vessel is constructed using material low alloy steel of type ASME SA516Gr70.

Bandarupalli Praneethetal [2]: In this paper they have discussed on FE analysis of pressure vessel and piping design. The stresses developed in solid layer pressure vessel and multilayer pressure vessels are analysed. The theoretical and ANSYS results are compared. Finally it was concluded that theoretically calculated values are very close to that of the values obtained from ANSYS is suitable for multilayer pressure vessels. Multilayer pressure vessels are superior to the solid layer pressure vessel.

M. Giglio etal[3]:In this paper they have discussed on Fatigue analysis of different types of pressure vessel nozzle. He carried out comparison between the two different methods for the construction of pressure vessel nozzle. He concludes that failure of nozzles was by crack passing through their thickness. Both designs (integral and external reinforcement) give good fatigue life results.

Javad Marzbanrad etal[3]:In this paper they have discussed on FE analysis of composite high pressure hydrogen storage vessels. Composite pressure vessel is largely used in industrial applications such as softening, filtration and storage. In this design, Unit load method under various internal pressures and analysis was carried out in ABAQUS. The result shows that fatigue lifetime of vessel depends on crack density, stress induced in it and cyclic loading amplitude.

BHPV manual on Multilayer Pressure Vessel[4] et al has investigated There is a percentage saving in material of 26.02% by using multilayered vessels in the place of solid walled vessel. This decreases not only the overall weight of the component but also the cost of the material required to manufacture the pressure vessel. This is one of the main aspects of designer to keep the weight and cost as low as possible. The Stress variation from inner side to outer side of the multilayered pressure vessel is around 12.5%, where as to that of solid wall vessel is 17.35%. This means that the stress distribution is uniform when compared to that of solid wall vessel.

Minimization of stress concentration is another most important aspect of the designer. It also shows that the material is utilized most effectively in the fabrication of shell. Theoretical calculated values by using different formulas are very close to that of the values obtained from ANSYS analysis. This indicates that ANSYS analysis is suitable for multilayer pressure vessels. Owing to the advantages of the multi layered pressure vessels over the conventional mono block pressure vessels, it is concluded that multi layered pressure vessels are superior for high pressures and high temperature operating conditions.

Umbarkar Bhagyashri B etal[5]:In this paper they have discussed on the design and analysis of pressure vessel, the design of pressure vessel depends on its pressure and temperature. In pressure vessel design, the main consideration was safety and the structural integrity of mechanical components of pressure vessel requires fatigue analysis including stress analysis and thermal analysis and the Fatigue analysis also done on modelled in Pv Elite software to improve the life of pressure vessel. According to ASME SEC VIII DIV-2, Analysis of pressure vessel is carried out at different temperature and pressure conditions and concluded that the Fatigue analysis will be carried out to the equipment for specified regeneration cycles and found that fatigue life is more than the required cycles. Accordingly he concludes that all evaluation points for fatigue are within the allowable limits specified by the code.

Noel,M.R [6] et al has investigated Due to shrink fitting, compressive stresses developed in the layers counter tensile stresses induced due to internal pressure which results in decreased Hoop's stress. It is found that thickness required for shell of Mono Wall. Pressure vessel is higher than that of multi wall pressure vessel. Hence preference to multi wall vessel is justified both economically (material cost) and physically (material weight). Multi Wall Pressure Vessels are more useful in the high. Pressure applications than Mono Wall Pressure vessels. Thickness calculation of shell by ASME codes conforms. to Lami's theorem with very small error. Calculation on ANSYS gives the very small amount of. errors with the manually calculated quantities, which confirms the validity of design methodology

Harold H.Wait[7] has investigated Fatigue analysis will be carried out for entire equipment for specified regeneration cycles and we will found fatigue life more than required cycles. Accordingly we conclude that all evaluation points for fatigue are within allowable limits

III PROJECT OVER VIEW

3.1OBJECTIVE OF THE PROJECT:

In the below point the background of the project is stated

1) Brief study of pressure vessel types and working is discussed in this project.

2) Stress evaluation for pressure vessel by optimizing different ends Elliptical and flat conditions.

3) Modeling of pressure vessel is done in Catia v5 design software with wall thickness of 20 mm & diameter of 880mm.

4) Generally using materials are haste alloy, stainless steel but in this project selected for Pressure vessel is assigned two different materials such as one general material SA-516 GR.70 another one is Nimonic 80A Material.

5) Analysis purpose using Ansys software we are choosing two type of analysis static and steady state thermal analysis.

6) Working Pressure 0.824 MPa is applied on the inner section wall of pressure vessel.

Working temperature is 200^{o}c is applied on the inner section wall of the pressure vessel

7) Finally identification Stress, deformation, Heat flux values as a result due to pressure is noted and concluded which material can sustain max pressure based on these values stress , deformation. And heat flux.

3.2METHODOLOGY:

1. To achieve the above objective the following methodology has been adopted in the present work as shown below figure 11 process of Metholodogy
2. A pressure vessel is select the two heads in this project Elliptical and Flat head
3. Modeling of the pressure vessel is done using catia software.
4. The model is imported to Ansys and analysis is preformed as follows.
5. .Material properties are added.
6. Meshing is done, finally static and thermal boundary conditions are applied & it is solved.
7. After solution the results are viewed in general postprocessor and check stress, deformation and Heat flux.
8. Then the results from the analytical method Shown in graphical method concluded the suitable material

3.3PROBLEM DEFINITION:

Improper design and material leads to the failure because Humidity, temperature, rain, wind, impurities and metal wet times have an effect on the pressure corrosion rate Corrosion reaction Basically the metallic pressure vessels are having good strength but due to their high weight to strength ratio and corrosive properties they are least preferred in aerospace as well as oil and gas industries. These industries are in need of pressure vessels which will have low weight to strength ratio without affecting the strength in this project pressure vessel with wall thickness of 20mm and diameter of 880mm is used with different different designs and materials is possible generally when the temperature is above 0°C and the relative humidity is over 80% (the surface is wet). Air impurities that dissolve in condensed water or rain water may accelerate corrosion. Settling of dust and dirt on the metal surface accelerates atmospheric corrosion.

3.4MAJOR MODELLED DIMENSIONS OF THE DEMO VESSEL:

Shell outside diameter D	880 mm
Shell length L	1520mm
Spherical head outside diameter	880mm
Corrosion allowance	1.28mm
Thickness of all ribs , tr	16mm
Distance b/w saddles, ds	937.6mm
Height of ribs, Hr	470mm
Width of rib Wr	176mm
Length of base plate	815mm
Saddle angle, θ	120°
Shell angle, (j)	117.4°
Thickness of all plates (shell), ts	20 mm

Figure 3 Parameters of pressure vessel

3.5 MATERIAL PROPERTIES:

a) SA-516 GR.70 (CARBON STEEL) MATERIAL:

ASME SA 516 70 grade is one of the most popular steel grades in market . It is primarily intended for use in welded pressure vessels where notch toughness is important. It comes in four grades 55, 60, 65 & 70. high quality carbon steel plate for boiler and pressure vessel fabrication which is ideally suited to the high standards set by the oil, gas and petrochemical industry - this is why we stock an extensive range of carbon plates according to ASTM A516 Grade 70 and ASME SA516 Grade 70. The purpose of heat treating carbon steel is to change the mechanical properties of steel, usually ductility, hardness, yield strength, or impact resistance. Note that the electrical and thermal conductivity are only slightly altered and mostly used pressure vessels.

b) NIMONIC 80A MATERIAL:

NIMONIC alloys are primarily composed of nickel and chromium. These alloys are known for their high-temperature low-creep and high performance. Additives like aluminium, carbon and titanium are infused into the alloy. NIMONIC alloys available commercially are NIMONIC 75, NIMONIC 80A, NIMONIC alloy 80A is a wrought, age-hardened alloy that is strengthened by additives like titanium, aluminium and carbon. It is manufactured by high-frequency melting and casting in air. It is similar to NIMONIC alloy 75. It has good corrosion and oxidation resistance. The creep rupture and tensile properties are high at 815°C (1500°F). widely used in boilers, turbine blades, combustion chambers, pistons ,machinery tools.

MATERIAL PROPERTIES	NIMONIC 80A	SA-516 GR.70 (CARBON STEEL)
Density(g/cc)	8.19	7.80
Ultimate tensile strength(Mpa)	890	550
Modulus of Elasticity(Gpa)	185	200
Poisson's Ratio	0.30	0.29
Thermal conductivity (W/m-k)	55	46
Specific Heat Capacity (J/g-°C)	0.448	0.460

Table 1 MATERIALPROPERTIES

IV INTRODUCTION OF CATIA

4.1 INTRODUCTION TO CATIA V5R20:

Welcome to **CATIA (Computer Aided Three Dimensional Interactive Application)**. As a new user of this software package, you will join hands with thousands of users of this high- end CAD/CAM/CAE tool worldwide. If you are already familiar with the previous releases, you can upgrade your designing skills with the tremendous improvement in this latest release.CATIA V5, developed by Dassault Systems, France, is a completely re-engineered, Next- generation family of CAD/CAM/CAE software solutions for Product Lifecycle Management.

4.2 DESIGN PROCEDURE IN CATIA:

4.2.1 ELLIPTICAL HEAD : Go to the sketcher workbench select xy plane create the sectional view as per the dimensions length is 1520 height is 440 and create the offset distance is 440 apply fillet radius is 440 after go to the part design workbench apply shaft 360^{o} .

Now go to the reference element offset distance is 750 create the saddle as per the dimensions after apply pad 100mm . After create the mounting components go to the offset distance from surface of boiler create the two circles and pad apply pad again go to the top surface create the again two circle apply circular pattern apply pad. after go to the part design apply mirror as shown below figure.

Figure 4Elliptical head

4.2.2FLATE HEAD : Go to the sketcher workbench select xy plane create the sectional view as per the dimensions length is 1520 height is 440 and create the offset distance is 440 apply fillet radius is 50 after go to the part design workbench apply shaft 360^{o} .

Now go to the reference element offset distance is 750 create the saddle as per the dimensions after apply pad 100mm . After create the mounting components go to the offset distance from surface of boiler create the two circles and pad apply pad again go to the top surface create the again two circle apply circular pattern apply pad. after go to the part design apply mirror as shown below figure.

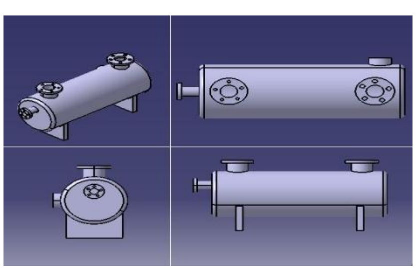


Figure 5 Flate head in catia

V INTRODUCTION TO ANSYS:

ANSYS is a large-scale multipurpose finite element program developed and maintained by ANSYS Inc. to analyze a wide spectrum of problems encountered in engineering mechanics**.**

5.1ANALYSIS PROCEDURE IN ANSYS:

Designed component in CATIA V5 workbench after imported into ANSYS workbench now select the steady state thermal ANALYSIS.

1) ENGINEEERING MATERIALS (MATERIAL PROPERTIES).
2) CREATE OR IMPORT GEOMENTRY.
3)MODEL (APPLY MESHING).
4)SET UP (BOUNDARY CONDITIONS).
5)SOLUTION.
6)RESULT.

5.2 STATIC STRUCTURAL ANALYSIS

The static structural analysis calculates the stresses, displacements, strains, and forces in structures caused by a load that does not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that the loads and the structure's response are assumed to change slowly with respect to time. A static structural load can be performed using

the ANSYS WORKBENCH solver. The types of loading that can be applied in a static analysis include:

5.2.1MESHING:

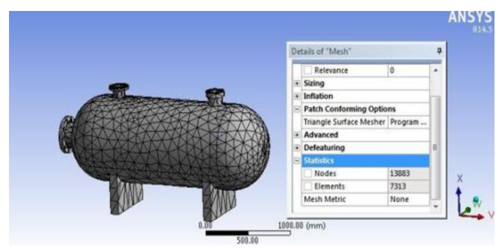


Figure 6 Mesh of Elliptical head

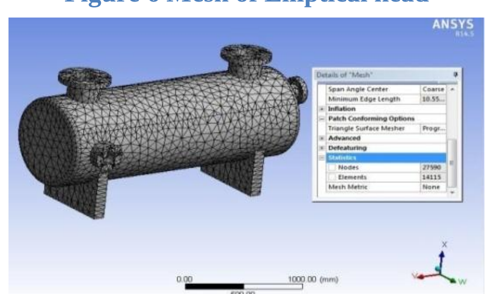


Figure 7 Mesh of flat head

pressure vessels should be made in carbon steel but in this project used nimonic 80A material because high strength material and non corrosion material.

5.2.2 BOUNDARY CONDITIONS:

1. Maximum working pressure load apply at inside on pressure vessel surface of the 0.824 Mpa.

2. Temperature apply at the inside on pressure vessel surface top surface 200ºc.

3. Fixed the saddles Bottom of the pressure vessel as shown in below figure 23,24,2,5,26 Boundary condition of flat head pressure vessel in static analysis, Boundary condition of flat head pressure vessel in Thermal analysis, Boundary condition of Elliptical head pressure vessel in static analysis, Boundary condition of Elliptical head pressure vessel in Thermal analysis.

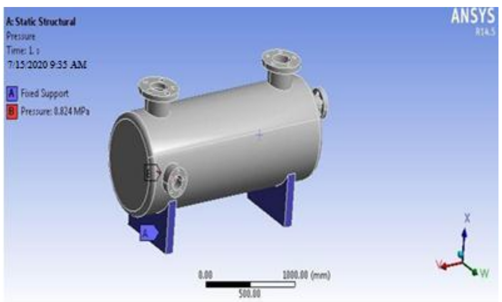


Figure 8 STATIC BOUNDARY CONDITIONS

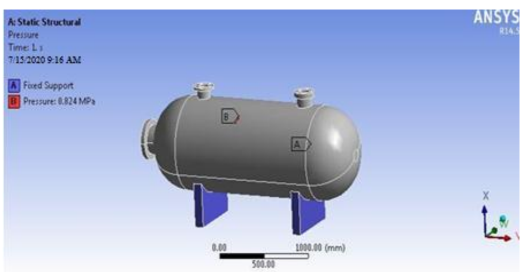


Figure 9 STATIC BOUNDARY CONDITION

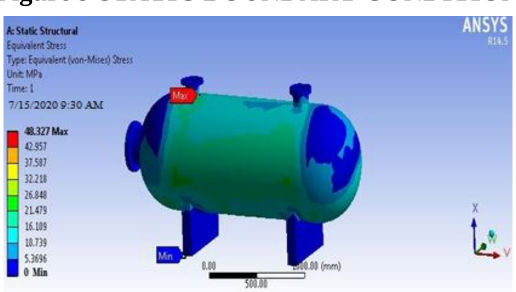


Figure 10 Von-misses stress of elliptical head

Figure 11 boundary condition in thermal analysis

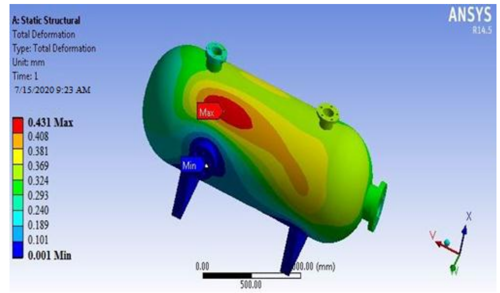


Figure 12 Total deformation of elliptical head

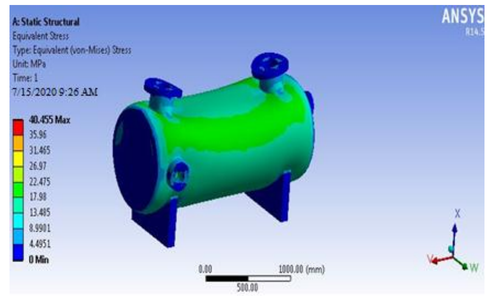


Figure 13 Von-misses stress of flat head

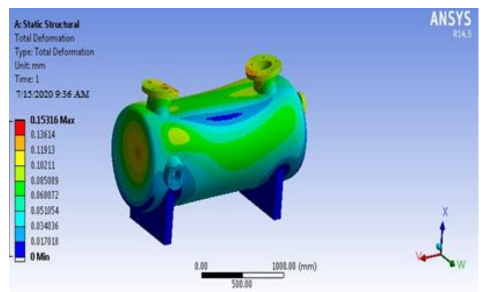
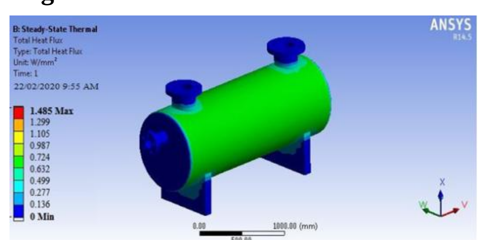


Figure 14Total deformation of flat head



Total heat flux of Nimonic 80A Material

VI RESULTS AND DISCUSSION

This analysis is performed to find Structural and thermal parameters such as Stresses, Deformation, heat flux, of horizontal pressure vessel and saddle support with two designs and two materials in this project boiler and saddle designed in Catia and analysis using Ansys fixed the bottom of saddle and apply boundary conditions on pressure vessel as shown final figures.

6.1 VON-MISES STRESS GRAPH :

The below graph shows that Variation of stresses Two different designs elliptical head and flat head and two different materials SA-516 GR.70 (CARBON STEEL)

MATERIALNIMONIC 80A, finally Nimonic 80A and flat head least stress as shown below figure.

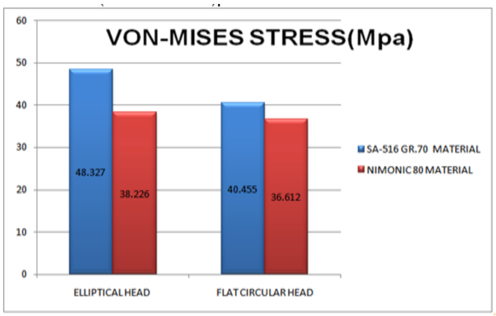


Figure 15 Von-misses stress graph

6.2 TOTAL DEFORMATION GRAPH:

The below graph shows that Variation of deformation Two different designs and two different materials SA-516 GR.70 (CARBON STEEL) MATERIAL , NIMONIC 80A, finally Nimonic 80A and flat head is the least deformation as shown below figure.

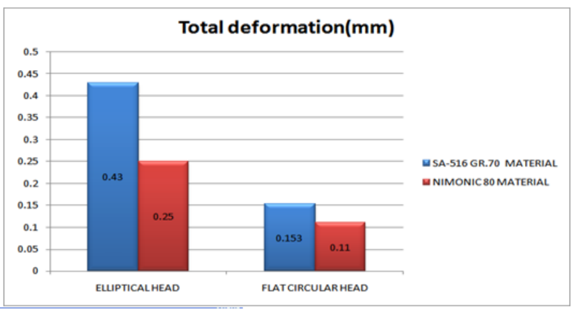


Figure 16 Total deformation Graph

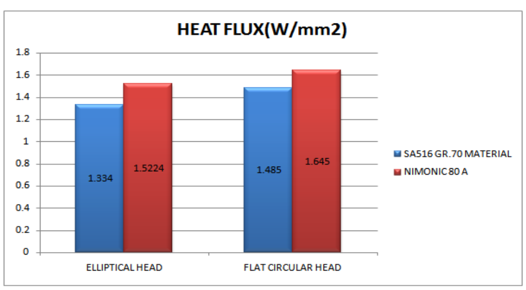


Figure 17 Total heat flux

VII 7 CONCLUSION

Pressure vessels are defined in American Society of Mechanical Engineer section VIII, Div 1 introduction as "Pressure vessels are containers for containment of pressure either external or internal. The pressure may be from an external source, or by application of heat from a direct or indirect source. Modeling of horizontal pressure vessels elliptical and flat head is done by using CATIA Software and then the model is imported into ANSYS Software for Structural and thermal analysis on pressure vessel to check the quality of materials such as, SA-516 GR.70 (CARBON STEEL) MATERIAL , NIMONIC 80A .Generally pressure vessels are made up of haste alloy ,inconel, stainless steel materials.From the obtained Von-misses stresses, , deformation, and heat flux for the materials, respectively Compared with two different materials with different heads Finally Nimonic80A material have less stresses, deformations, and heat flux values .Finally from structural analysis and thermal analysis based on results it is concluded that with holes Nimonic80A material is suitable material for pressure vessel material because of NIMONIC alloys are primarily composed of nickel and chromium. These alloys are known for their high-temperature low-creep and high performance. NIMONIC alloy 80A is a wrought, age-hardened alloy that is strengthened by additives like titanium, aluminium and carbon. It is manufactured by high-frequency melting and casting in air. It is similar to NIMONIC alloy 80A It has good corrosion and oxidation resistance than it is suitable for manufacturing process

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