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DESIGN AND ANALYSIS OF PRESSURE VESSEL USING DIFFERENT MATERIALS

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ABSTRACT

This project explores the field of Finite Element Analysis (FEA) in relation to pressure vessels that have different head configurations, while ensuring that the cylindrical volume and thickness remain uniform. The project adheres to ASME standards, specifically Section VIII, Division I, and focuses on designing a pressure vessel that can withstand a pressure of 8 bar within a volume of 24 liters. The main objective of using FEA is to identify areas of stress concentration in each head design. In industrial settings, pressure vessels play a crucial role in containing fluids or gases under varying pressures. The choice of head configuration significantly impacts the distribution of stress and the overall structural strength. This project specifically utilizes ANSYS software for static and thermal analyses to compare stress distribution in pressure vessels with flat heads, elliptical heads, and other common head designs. The goal is to identify configurations that exhibit lower stress levels, with a particular emphasis on practical scenarios that favor elliptical heads. Additionally, the project explores finite element modeling techniques to evaluate pressure vessels made from different materials such as Nimonic 80A and SA516 Gr70 under high-stress conditions

1. INTRODUCTION

1.1 INTRODUCTION TO PRESSURE VESSELS

Pressure vessels are enclosed containers that are utilized in a range of industries, including petrochemical, oil and gas, chemical, and food processing. These vessels are designed to hold liquids, vapors, and gases at pressures that are significantly higher or lower than the surrounding atmospheric pressure. Examples of pressure vessels include reactors, flash drums, separators, and heat exchangers. It is crucial to ensure that pressure vessels are designed with utmost care to prevent any leakage, especially considering the combination of high pressure, high temperature, and potentially flammable or radioactive materials. The safety and integrity of these vessels rely on meticulous design and construction to withstand the demanding conditions they are subjected .

The first recorded pressure vessel design can be traced back to Leonardo da Vinci's Codex Madrid I in 1495. Nevertheless, this design differed significantly from modern pressure vessels in terms of usage area and features. The predecessors of today's pressure vessels began to emerge in the 1800s during the industrial

Figure 1 Pressure vessel

FIGURE 2 TYPES OF BOILERS

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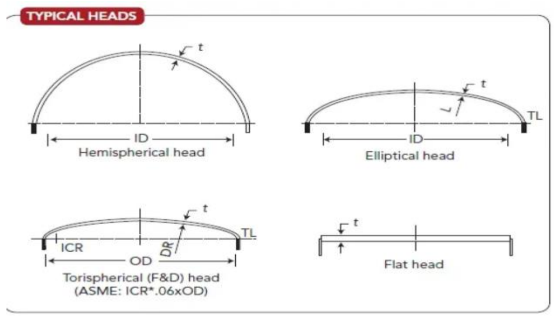

Figure 3 different types of heads of pressure vessel

1.2 Different types of heads are discussed in brief below:

1.2.1 FLAT HEADS : Utilized exclusively for small vessels, flat heads or plates represent the most straightforward type of end closures. Their functionality extends to serving as manhole covers in low pressure vessels and as covers for smaller openings..

1.2.2 HEMISPHERICAL HEADS: The hemispherical head is characterized by a straightforward radial geometry: its depth is half the diameter. For a 47" ID, a wall thickness of 0.2474" is required, roughly half of the shell's thickness. A 3:1 taper is utilized on the transition due to the head being thinner than the shell.

Typically, a hemispherical head is not crafted from a flat sheet; rather, it is fabricated from welded components, resulting in the thinnest head that can be quite costly. This type of head is frequently used in applications requiring large diameters or high pressures, underscoring the importance of material conservation. When two spherical heads are positioned back to back, they create a storage sphere, which is considered the most efficient shape for pressurized storage

1.2.3 ELLIPSOIDAL HEADS: The ellipsoidal head, also known as the elliptical head, is a unique type of head consisting of two main components: a rotating ellipsoidal sphere and a straight cylindrical section. Unlike other tank heads, the elliptical tank head is not defined by a fixed dish radius or knuckle radius. Instead, it is fabricated to have a specific shape. The dish radius is approximately 90% of the diameter, while the knuckle radius is approximately 17% of the diameter. It is important to mention that 2:1 elliptical flanged and dished heads comply with the ASME standards.

1.2.4 TORISPHERICAL HEADS: The torispherical shape is a popular choice for end closures in cylindrical pressure vessels because of its ease of fabrication and lower cost compared to ellipsoidal shapes. To mitigate excessive local stresses, a transition section known as a knuckle is incorporated between the dish and the cylinder.

1.2.5 CONICAL HEADS: The use of conical heads as bottom heads is prevalent for fluid removal or drainage purposes. A semi-cone angle of 30° is typically applied.1.3 TYPES OF PRESSURE VESSELS

(a)According to dimension:

i. Thin Pressure vessel d/t > 20
ii. Thick Pressure vessel d/t< 20 1.4.2

(b)According to shape:

i. Cylindrical ii. Spherical

(c) According to construction;

i. Vertical ii. Horizontal

FIGURE 4 BOILER WITH SADDLE

FIGURE 5 DIFFERENT TYPES OF PRESSURE VESSELS

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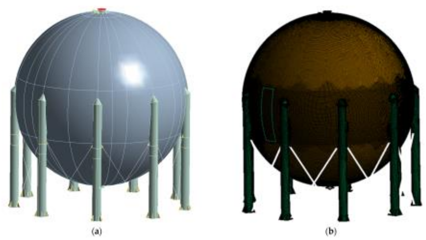

FIGURE 6 SPHERICAL PRESSURE VESSEL

1.4COMPONENT OF PRESSURE VESSEL:

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

1.5 ADVANTAGES OF PRESSURE VESSELS:

- A tension vessel can hold huge volumes of substances inside a minimal space.
- They can be designed to meet exact necessities, representing the substance, the working tension and temperature, and the space accessible for establishment.
- Pressure vessels are constructed observing quality guidelines and rules laid out by associations like the American Culture of Mechanical Architects (ASME).
- The vessels can take on different structures, from tube shaped tanks to round compartments and, surprisingly, more mind boggling calculations
- One of the benefits of strain vessels is their low working expense, ascribed to their insignificant support prerequisites and high erosion obstruction.

2. LITERATURE REVIEW

1. V. V. Wadkar, S.S. Malgave, D.D. Patil, H.S. Bhore, P. Gavade Colleague Teacher, Mechanical Office, Aitrc, Vita, India. This study is about a portion of the ongoing improvements in the assurance of stress fixation figure pressure vessels. The writing has demonstrated a developing interest in the field of pressure fixation examination in the tension vessels. Pressure vessels find wide applications in warm and thermal energy stations, cycle and synthetic ventures, in space, sea profundities and liquid stock frameworks in businesses. The primary goal of this study is to plan and dissect the elements of tension vessels. Different boundaries of Strong Strain Vessel are planned and checked by the standards determined in American Culture of Mechanical Specialists (A.S.M.E) Sec VIII Division 1. The burdens created in Strong wall pressure vessel and Head of strain vessel is broke down by utilizing ANSYS, a flexible Limited Component Bundle. The hypothetical qualities and ANSYS values are thought about for both strong wall and Head of tension vessels.

2. Aziz onder, onursayman, tolgadogan, necmettintarakciogluSelcuk College, branch of mechanical designing, Konya, turkey. In this review, ideal point employ directions of symmetric and antisymmetric [h/h] s shells intended for most extreme burst pressure were analyzed. Burst tension of fiber wound composite strain vessels under rotating unadulterated inside pressure was explored. The review manages the impacts of temperature and twisting point on fiber wound composite tension vessels. Limited component strategy and trial approaches were utilized to confirm the ideal winding points. A flexible arrangement system in light of Lekhnitskii's hypothesis was created to foresee the burst disappointment tension of the strain vessels.

3. A.th. Diamantoudis, th.Kermanidis research center of innovation and strength of materials, division of mechanical designing and flying, college of Patras. A similar report for plan by examination and plan by equation of a chamber to spout convergence has been made utilizing different limited component strategies. The chamber to spout convergence examined is important for a regular vertical strain vessel with a skirt support. For the review the regularly utilized flexible P355 steel amalgam and the high strength steel combination P500 QT were thought of. The similar outcomes obviously show burdens as far as cutoff load ability when the plan by-recipe techniques are utilized in the plan of high strength steel pressure vessels. The FE results likewise obviously show benefits of the shell to strong sub-demonstrating procedure, as it joins the exactness of 3D-strong displaying with the reasonable figuring season of the 3D-shell displaying method.

4. Aniruddha A. Sathe, Vikas R. Maurya, Shriyash V. Tamhane, Akshaya P. Save, Parag V. NikamBachelor of

Designing Understudies, and Colleague Teacher Division of Mechanical Designing, St. John School of Designing and The executives, Palghar(E), Palghar, India The point of this undertaking isto play out the itemized plan and investigation of strain vessel for ideal thickness utilizing SOLIDWORKS programming. The chose parts of tension vessel like Shell, Heads, Spouts, Supports and Lifting Drags and so on are contrasted and Standard accessible thickness and improvement being finished for the reasonable anxieties for MOC. The thickness of the strain vessel is checked for various burden cases. This outcomes in the improvement of strain vessel part thickness and hence reduces the overall weight and the cost the The The pressure vessel is designed with an optimal wall thickness to meet the service conditions effectively. The optimized pressure vessel ensures that it can endure all the applied conditions throughout its service life, maintaining the same safety factor as the existing model but with a reduced weight.

5. Davidson, Thomas E. Kendall, David P. WATERVLIET ARSENAL NY BENET WEAPONS LAB The report is a review of the theory and practice of pressure vessel design for vessels operating in the range of internal pressures from 1 to 55 kilobars approximately 15,000 to 800,000 psi and utilizing fluid pressure media. The fundamentals of thick-walled cylinder theory are reviewed, including elastic and elastic-plastic theory, multi-layer cylinders and autofrettage. The various methods of using segmented cylinders in pressure vessel design are reviewed in detail. The factors to be considered in the selection of suitable materials for pressure vessel fabrication are discussed.

6. Mackenzie, A. Dalrymple, E. W. Schwartz, F. PICATINNY ARSENAL DOVER NJ FELTMAN RESEARCH LABS. The report contains special sections on the design of end closures, shock attenuation, providing for electrical lead-throughs needed for instrumentation, and the use of a thin window in the vessel needed for irradiation experiments. From this information a pressure vessel for a particular application can be designed.

7. W. S. PELLINI, P. P. PUZAK Metallurgy Division, U. S. Naval Research Laboratory, Washington, D.C. Practical Considerations in Applying Laboratory Fracture Test Criteria to the Fracture-Safe Design of Pressure Vessels. This report presents a "broad look" analysis of the opportunities to apply new scientific approaches to fracture safe design in pressure vessels and of the new problems that have arisen in connection with the utilization of higher-strength steels. These opportunities follow from the development of the fracture analysis diagram which depicts the relationships of flaw size and stress level for fracture in the transition range of steels which live well-defined transition temperature features.

8. T.R. Tauchert department of engineering mechanics university of Kentucky Lexington. The distribution of fibres in a cylindrically reinforced pressure vessel of given size and constituent properties is optimized using the criterion of minimum strain energy. A stress function approach, in conjunction with the modified Rayleigh-Ritz technique, is employed to obtain an approximate solution to the non-linear optimization problem. Constraint conditions include specification of the global volume fraction of fibres and satisfaction of stress boundary conditions. Numerical results are presented for reinforced cylinders having various radii, modulus ratios, and global volume fractions. Included is the case of a reinforced concrete cylinder, in which the concrete is assumed to be ineffective in tension. In most cases examined, use of the optimum fibre distribution, rather than a uniform distribution, results in a substantial reduction in the maximum radial displacement and an increase in the failure pressure load.

9. LevendParnas, NuranKatirci Department of Mechanical Engineering, Middle East Technical University, 06531 Ankara, Turkey. An analytical procedure is developed to design and predict the behaviour of fibre reinforced composite pressure vessels. The classical lamination theory and generalized plane strain model is used in the formulation of the elasticity problem. Internal pressure, axial force and body force due to rotation in addition to temperature and moisture variation throughout the body are considered. Some 3D failure theories are applied to obtain the optimum values for the winding angle, burst pressure, maximum axial force and the maximum angular speed of the pressure vessel. These parameters are also investigated considering hygrothermal effects.

10. Piotr Dzierwa Faculty of Mechanical Engineering, Cracow University of Technology.Optimum Heating of Pressure Vessels with Holes. A method for determining time-optimum medium temperature changes is presented. The heating of the pressure elements will be conducted so that the circumferential stress caused by pressure and fluid

temperature variations at the edge of the opening at the point of stress concentration does not exceed the allowable value. In contrast to present standards, two points at the edge of the opening are taken into consideration. Optimum fluid temperature changes are assumed in the form of simple time functions. It is possible to increase the fluid temperature stepwise at the beginning of the heating process and then the fluid temperature can be increased with a constant rate.

3. PROJECT OVER VIEW

3.1 OBJECTIVE OF THE PROJECT:

In the below point the background of the project is stated

In this project, a brief overview of pressure vessel types and operation is covered.
2) Stress assessment for pressure vessel by maximizing flat, toriconical head, and hemispherical end conditions.
3) A pressure vessel with a diameter of 880 mm and a wall thickness of 20 mm is modeled using the Catia v5 design program.
4) SA-516 GR.70 (CARBON STEEL) MATERIAL and HSLA are typically used, however two distinct materials—one generic material, NIMONIC 80A, and the other, Nimonic75 Material—are assigned to this project for the pressure vessel.
5) We are selecting between two types of analysis utilizing Ansys software: static and steady state thermal analysis.
6) A working pressure of 0.824 MPa is applied to the pressure vessel's inner section wall.
The inner wall of the pressure vessel is heated to a working temperature of 200 degrees Celsius.
7) The determination of stress, deformation, and heat flux values resulting from pressure is the final step. Based on these data, it is determined which material can withstand the maximum amount of pressure.

3.2 METHODOLOGY:

1. To achieve the above objective the following methodology has been adopted in the present work.
2. A pressure vessel is select the two heads in this project hemi spherical, toriconical head and flat conditions
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**

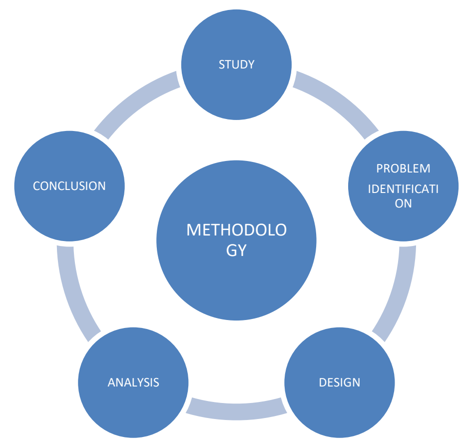

FIGURE 7 METHODOLOGY

3.3 PROBLEM 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.

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FIGURE 8 PROBLEMS OF PRESSURE VESSELS

3.5 MAJOR 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, 0	**120º**
Shell angle, (j)	**117.4º**
Thickness of all plates (shell), ts	**20 mm**

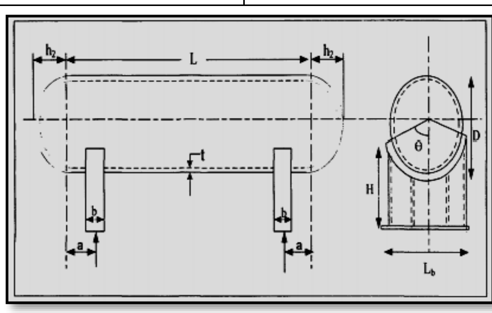

FIGURE 9 SPECIFICATION OF PRESSURE VESSEL

3.6 MATERIAL PROPERTIES:

Material	Density (g/cm³)	Young's Modulus (GPa)	Poisson's Ratio	Thermal Conductivity (W/(m·K))	Specific Heat Capacity (J/(kg·K))
High-Strength Low-Alloy Steel	7.85	200	0.3	45	460
Nimonic 75	8.37	220	0.33	11	410
SA-516 Gr.70 (Carbon Steel)	7.85	200	0.3	52	470
Nimonic 80A	8.19	220	0.33	11	410

FIGURE 10 MATERIAL PROPERTIES

3.7TAKING WORKING CONDITIONS:

Design Pressure= 0.824E+6 N/m^2

Design Temperature= 200^0c

3.8 DESIGN CALCULATION:

are given by the following equations.

$$\sigma_3 = \frac{P \times R_m}{2 \times t} - \frac{M_1}{\pi \times R_m^2 \times t}$$

$$\sigma_3 = \frac{8.45 \times 428.64}{2 \times 14.72} - \frac{-113.3}{\pi \times 428.64^2 \times 14\ 72}$$

$$= 124.32 kgf/cm^2 \qquad \ldots\ldots (5)$$

Longitudinal stress at the bottom of the shell at support $\sigma_4 = \frac{P \times R_m}{2 \times t} + \frac{M_1}{\pi \times R_m^2 \times t}$

$$\sigma_4 = \frac{8.45 \times 428.64}{2 \times 14.72} + \frac{-113.3}{\pi \times 428.64^2 \times 14.72}$$

$$= 121.66 kgf/cm^2 \qquad \ldots\ldots (6)$$

T is the total shear force induced on the saddle support and it is determined by the following equation 7.

Maximum shear force in the saddle $T = \frac{Q \times (L - 2 \times a)}{L + \frac{4}{3} h_2}$

$$= \frac{1549 \times (152 - 2 \times 20.32)}{152 + \frac{4}{3} \times 421.28}$$

$$= 828.7 kgf \qquad \ldots\ldots. (7)$$

4. INTRODUCTION TO CATIA V5R20

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 provides three basic platforms: P1, P2, and P3. P1 is for small and medium-sized process-oriented companies that wish to grow toward the large scale digitized product definition.

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 360º .

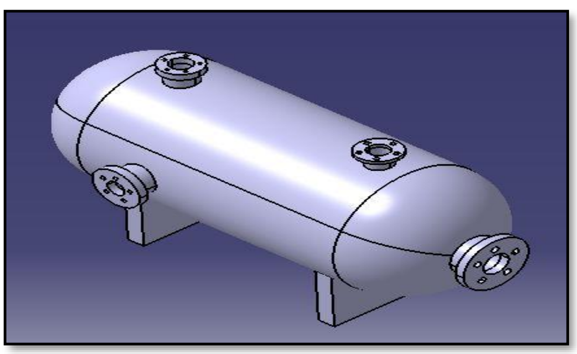

FIGURE 11 ELLIPTICAL HEAD IN CATIA

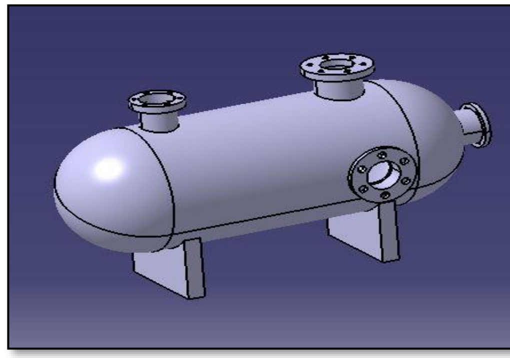

FIGURE 1 ISOMETRIC VIEW IN CATIA WORKBENCH

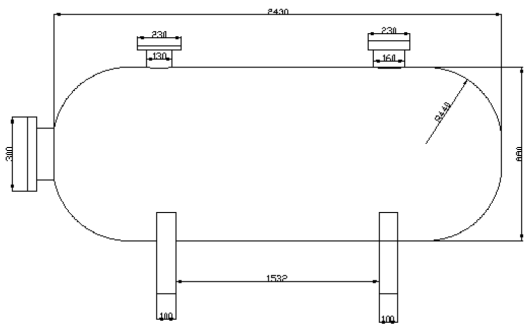

FIGURE 2 ELLIPTICAL HEAD DIMENSIONS

4.2.2 FLATE 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 360º .

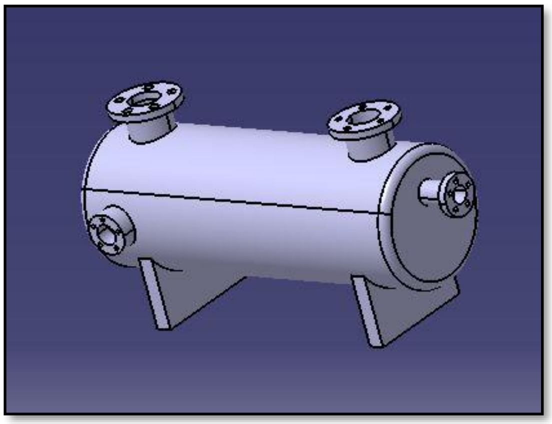

FIGURE 3 ISOMETRIC VIEW FLATE HEAD

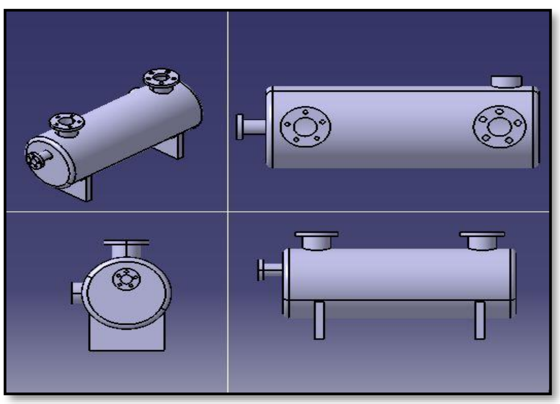

FIGURE 15 FLAT HEAD MULTIVIEWS

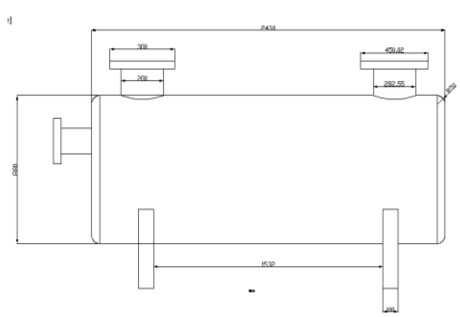

FIGURE 16 DIMENSIONS OF FLATE HEAD PRESSURE VESSEL

5. INTRODUCTION TO ANSYS

5.1 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**.**

5.2 PROGRAM ORGANIZATION:

The ANSYS program is organized into two basic levels:

- Begin level
- Processor (or Routine) level

The Begin level acts as a gateway into and out of the ANSYS program. It is also used for certain global program controls such as changing the job name, clearing (zeroing out) the database, and copying binary files. When you first enter the program, you are at the Begin level. At the Processor level, several processors are available.

6. FINITE ELEMENT METHOD

6.1 INTRODUCTION:

The Basic concept in FEA is that the body or structure may be divided into smaller elements of finite dimensions called “Finite Elements”. The original body or the structure is then considered as an assemblage of these elements connected at a finite number of joints called “Nodes” or “Nodal Points”.

Simple functions are chosen to approximate the displacements over each finite element. Such assumed functions are called “shape functions”. This will represent the displacement with in the element in terms of the displacement at the nodes of the element.

6.3.1 HEMISPHERICAL HEAD:

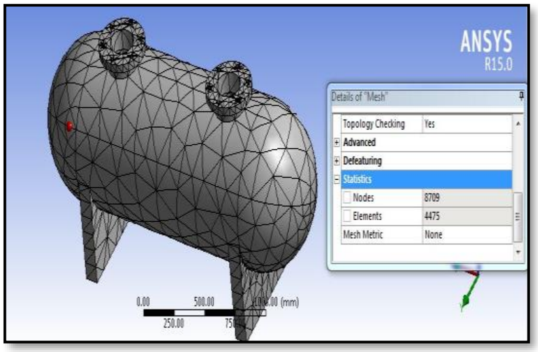

FIGURE 17 HEMISPHERICAL HEAD PRESSURE VESSEL MESH

6.3.2 FLAT HEAD:

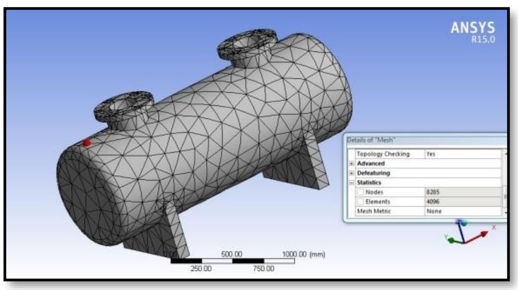

FIGURE 18FLAT HEAD PRESSURE VESSEL MESH

6.3.3 TORICONICAL HEAD:

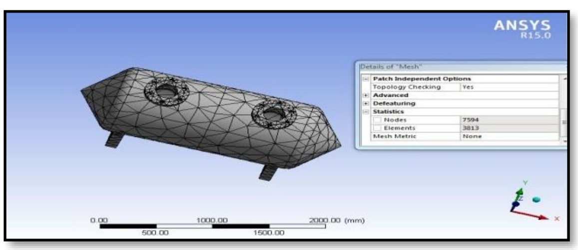

FIGURE 19TORICONICAL HEAD PRESSURE VESSEL (MESH: NODES 7594, ELEMENTS: 3813)

6.4 BOUNDARY CONDITIONS:

6.4.1 HEMISPHERICAL HEAD:

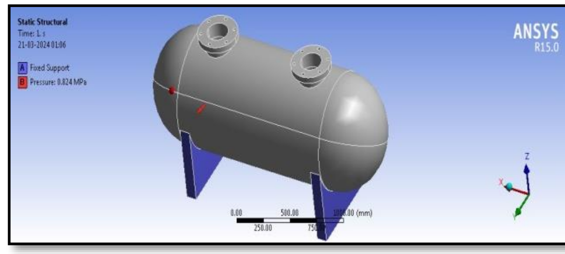

FIGURE 20 BOUNDARY CONDITION OF HEMISPHERICAL HEAD PRESSURE 0.824

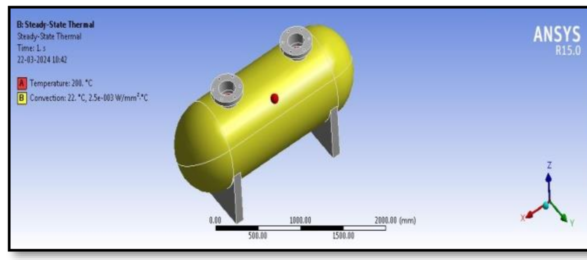

FIGURE 21 BOUNDARY CONDITION OF HEMISPHERICAL TEMPERATURE 200OC

6.4.2 FLAT HEAD:

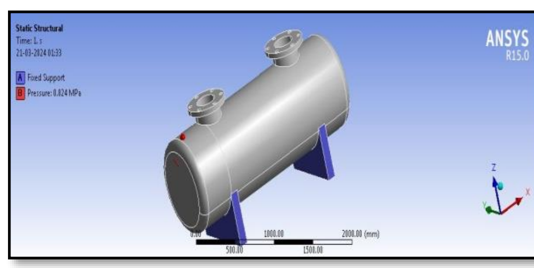

FIGURE 22 BOUNDARY CONDITION OF FLAT HEAD PRESSURE 0.824

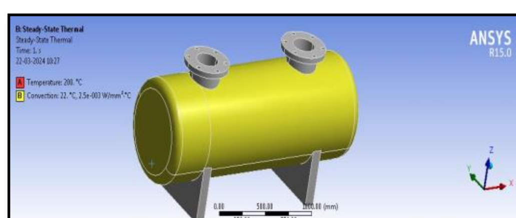

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FIGURE 23 BOUNDARY CONDITION OF FLAT HEAD TEMPERATURE 200OC

6.4.3 TORICONICAL HEAD:

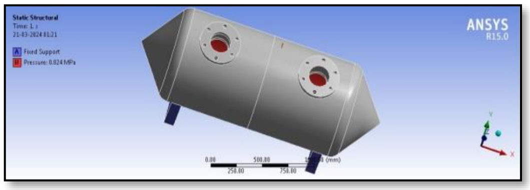

FIGURE 24BOUNDARY CONDITION OF TORICONICAL HEAD PRESSURE 0.824

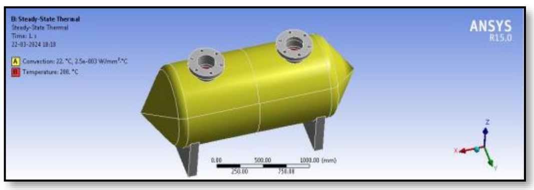

FIGURE 25BOUNDARY CONDITION OF TORICONICAL HEAD TEMPERATURE 200OC

7. RESULTS AND DISCUSSIONS

7.1 FLAT HEAD PRESSURE VESSEL

7.1.1 CARBON STEEL MATERIAL

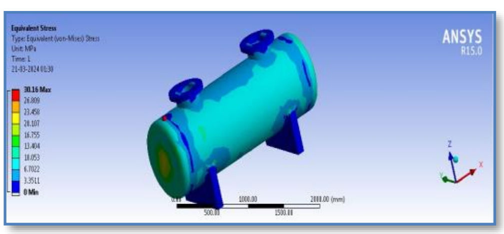

FIGURE 26 VON MISSES STRESSES OF FLAT HEAD CARBON STEEL MATERIAL

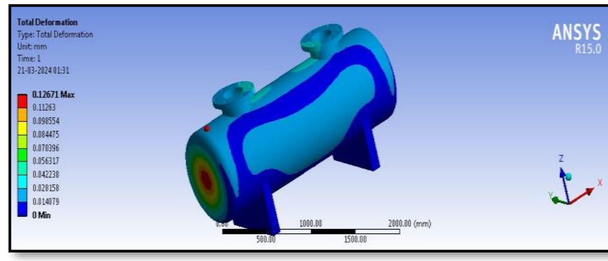

FIGURE 27 TOTAL DEFORMATION OF FLAT HEAD CARBON STEEL MATERIAL

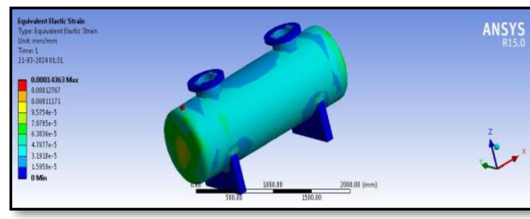

FIGURE 28 STRAIN OF FLAT HEAD CARBON STEEL MATERIAL

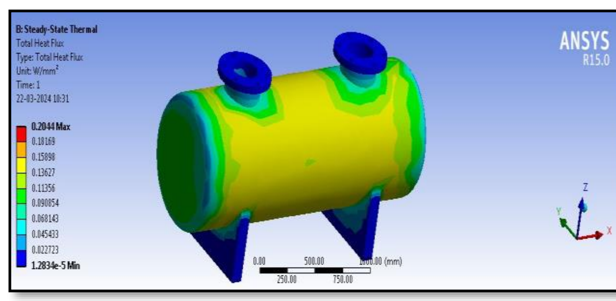

FIGURE 29 TOTAL HEAT FLUX OF FLAT HEAD CARBON STEEL MATERIAL

7.1.3 NIMONIC 75 MATERIAL

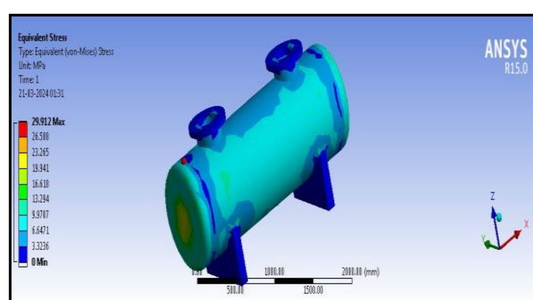

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FIGURE 30 VON MISSES STRESSES OF FLAT HEAD NIMONIC 75 MATERIAL

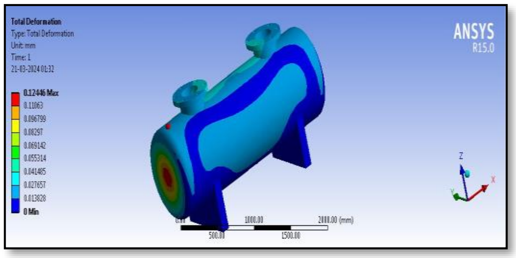


FIGURE 31 TOTAL DEFORMATION OF FLAT HEAD NIMONIC 75 MATERIAL

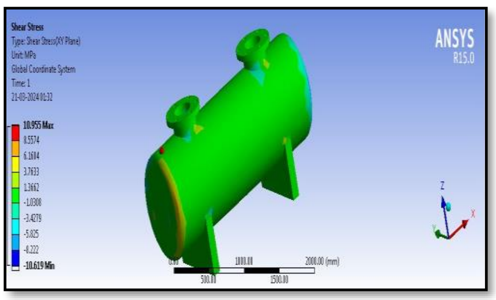


FIGURE 32 SHEAR STRESS OF FLAT HEAD NIMONIC 75 MATERIAL

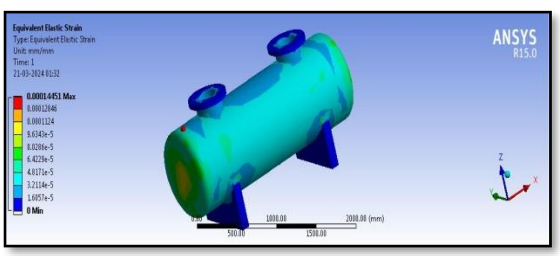


FIGURE 33 STRAIN OF FLAT HEAD NIMONIC 75 MATERIAL

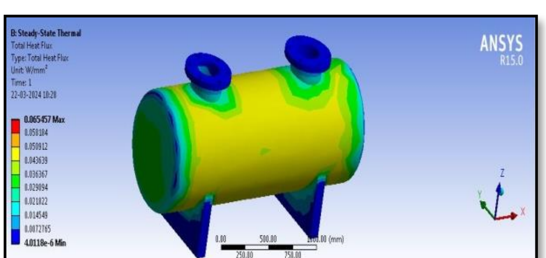


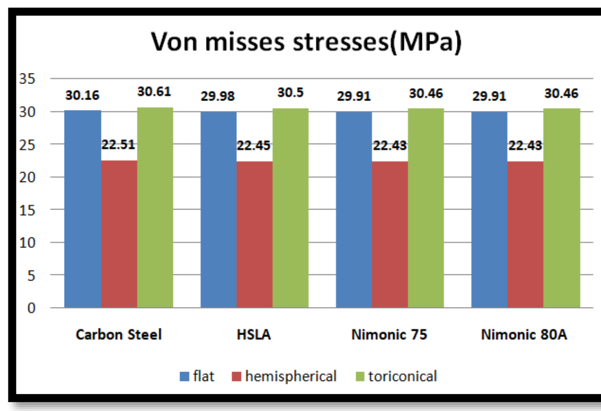
FIGURE 34TOTAL HEAT FLUX OF FLAT HEAD NIMONIC 75 MATERIAL

7.2 STATIC STRUCTURAL RESULTS

The below tabulated data is the maximum results obtained by all materials with the all three head shapes like flat, hemi spherical and toriconical shapes. The static structural von misses stresses, total deformation, shear stress and total deformation values are tabulated in below.

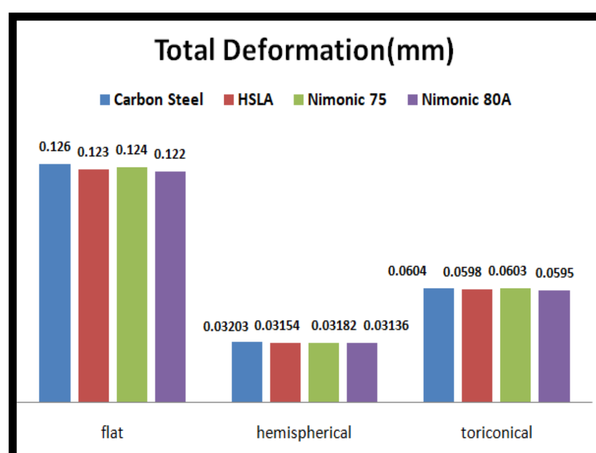
7.3 GRAPHS

7.3.1 VON MISSES STRESSES GRAPH:



GRAPH:1VON MISSES STRESSES

7.3.2 TOTAL DEFORMATION GRAPH:



GRAPH:2 TOTAL DEFORMATION

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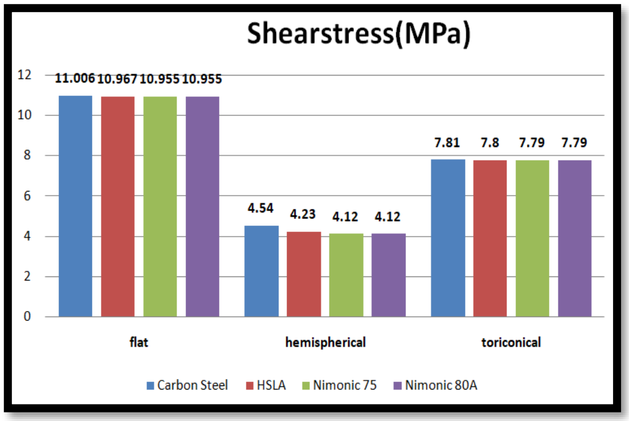
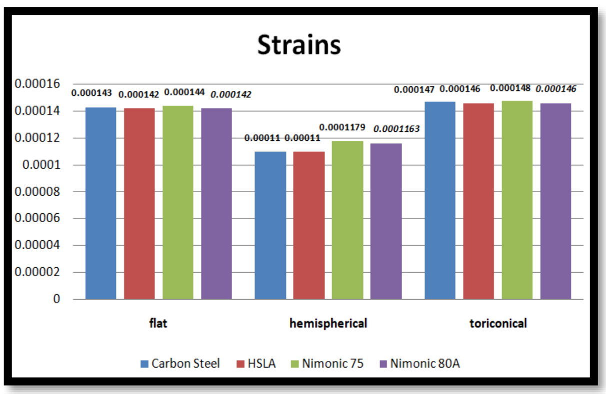
7.3.3 SHEAR STRESS GRAPH:



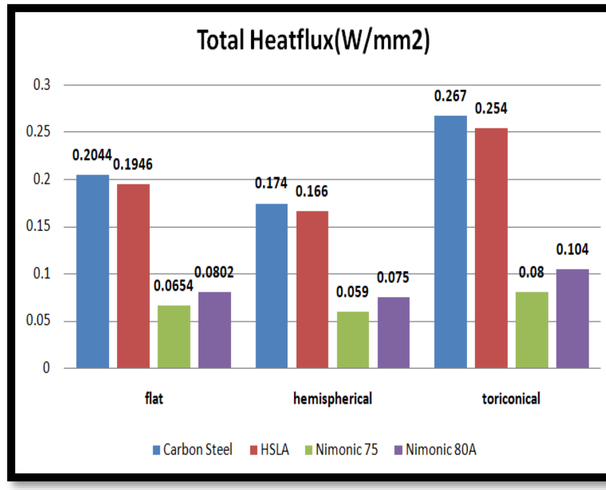
GRAPH:3 SHEAR STRESSES

7.3.4 STRAIN GRAPH



GRAPH:4 STRAIN GRAPH

7.3.5 TOTAL HEATFLUX GRAPH



GRAPH:5 TOTAL HEAT FLUX

8 CONCLUSION

The following conclusions have been drawn from the present work.

The pressure may be from an external source, or by application of heat from a direct or indirect source. Modeling of horizontal pressure vessels Flat head, Hemispherical head, Toriconicalhead 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, Four different materials SA-516 GR.70 (CARBON STEEL) MATERIAL, NIMONIC 75 MATERIAL, HSLA, NIMONIC 80A, Generally pressure vessels are made up of haste alloy materials. From the obtained Von-misses stresses, strain, total deformation, shear stress and heat flux for the materials, respectively Compared with four 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, aluminum 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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