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OPTIMIZATION OF PRESSURE VESSEL DESIGN FOR ENHANCED STRUCTURAL INTEGRITY AND SAFETY

Manish Kumar Assistant Professor, Department of Mechanical Engineering Saharsa College of Engineering, Saharsa, Bihar, India
Akhilesh Chandra Kashyap Assistant Professor, Department of Mechanical Engineering Saharsa College of Engineering, Saharsa, Bihar, India
Navin Kumar Assistant Professor, Department of Mechanical Engineering Rashtrakavi Ramdhari Singh Dinkar College of Engineering, Begusarai, Bihar, India

Abstract-
High-pressure, highly poisonous fluids are handled in pressure vessels, which are containers designed to withstand high pressure. Numerous industries, including the oil and gas, petroleum, beverage, chemical, power generating, and food sectors, among others, use pressure vessels. Pressure vessel failure can result in property damage, loss of life, and negative consequences on the surrounding community and industry. Pressure, temperature, material choice, corrosion, loadings, and a host of other variables that vary depending on the application all affect pressure vessel design. This paper outlines the efforts made in the design of pressure vessels in an effort to lower the number of vessel failures. It also studies many criteria, including material selection, operating pressure and temperature, design, and analysis.

Keywords –
Optimization, Pressure Vessel, Structural, Integrity, Safety, Numerous Industries.

INTRODUCTION
A container with a pressure differential from the atmosphere is called a pressure vessel. A pressure vessel is used to process or store high-temperature, high-pressure liquids. The fluid might be non-hazardous, like steam, or toxic, like chemicals. The pressure vessel must be designed in accordance with the commonly used standards, such as IS (Indian Standard) Code, EN/DIN (European) Code, and ASME (American Society of Mechanical Engineers) Section viii Division 1&2. In order to create standards that work for any application, these codes were created through experimentation. These codes are often created with a safety factor of three to 4.5 in mind. Pressure vessels are designed based on various criteria, including temperature, pressure, corrosion, and material choice. These parameters can be studied to aid in the vessel's design. There is a wide range of materials available; choose the one that best suits the purpose. A pressure vessel failure can result in property damage, human casualties, and system damage. Thus, techniques are created to prevent pressure vessel failures and the failures themselves are researched. Utilising tools like ANSYS, ABAQUS, PV Elite, Caesor, and others, as well as analytical techniques gleaned from the codes, the stresses generated in the vessel are examined and calculated. Software like PV Elite makes it easier to design and develop vessels quickly while producing correct results according to the chosen code. Additionally, precautions are made to ensure years of uninterrupted operation with little maintenance.

LITERATURE REVIEW
In order to create vessels with thinner shells, Y.Q. Lu and H. Hui conducted research on the mechanical behaviour of cold- and cryogenic-stretched austenitic stainless steel. The experiments included a series of tests on S30403 steel plate by r n n t to t mp r tur o C t w ol str t n s on n t - C t w cryogenic stretching can be done. The martensite transformations, strength, and plasticity properties exhibited by both methods were compared. FEA based on MISO technique was used to simulate cold- and cryogenic-stretched austenitic stainless steel. It has been found that cryogenic stretching can enhance a material's allowed stress by twice as much as cold stretching, which encourages a 60–75% decrease in vessel

thickness and produces a lighter vessel. The use of composite materials to substitute high strength to weight metals for pressure vessel use in low weight applications, such as aerospace and oil and gas, has been explained by Mr. Mukund Kavekar, Mr. Vinayak H. Khatawate, and Mr. Gajendra V. Patil. Epoxy resins and E-glass fibre plies with appropriate coatings are combined to create FRP laminates. They have compared the weight and stress of the composite and steel using ANSYS analysis. The maximum stress in the FRP composite was discovered to be lower than the maximum stress permitted by the FRP material. Compared to steel vessels, FRP vessels have greater structural efficiency. Additionally, a 75% weight reduction was achieved by employing FRP rather than steel, which also solved the steel corrosion issue.

The elements influencing the performance of the welded skirt support for vertical pressure vessels have been discussed by N.A. Weil and J.J. Murphy. It emphasises how important thermal impacts are. Analysis of local stresses is used to determine the fatigue basis for evaluating the vessel's performance. Throughout the process, they discovered that extra attention had to be paid to the weld's ability to support the vessel's weight, wind load, discontinuity forces, and moments. With temperature and vessel diameter, the thermal stresses are created, and their intensity rises approximately in the order Ta. The impact of baffling, insulation configurations, and the ratio of skirt to vessel thickness on thermal stresses are examined. The benefits of skirt slotting are also mentioned. The maximum local stress range, cycle count, and manufacturing quality are used to evaluate fatigue performance. It explains how cracks in skirt welding start and spread. There are specific advice and recommendations for fabrication and design techniques provided, along with welding specifics for increased strength and quality.

For most usage, it is recommended to use the lap-type attachment. A multi-layered high pressure vessel was designed by Siva Krishna Raparla and T. Seshaiah and compared with a monoblock vessel in their article. The process of creating multilayered pressure vessels involves covering the core tube with many sheets. There is opportunity to choose various materials at various tiers based on utility. Anti-corrosive materials can be used for the inner layer, while materials with high strength can be used for the outside layers. By using a multi-layered pressure vessel, the vessel's overall weight is reduced by 26.02%, representing a considerable savings percentage. With the aid of FEM software, it is discovered that the stress variation for a solid vessel is 17.35%, and for a multilayered vessel, it is 12.5%, leading to a more uniform distribution of stress. The multi-layered pressure vessels are therefore appropriate for applications involving high pressure and high temperature.

PRESSURE VESSEL DESIGN

Liquefied petroleum gas (LPG) is stored in the pressure vessel selected for this investigation. This pressure vessel is intended to be used stationary on a leg support and features elliptical heads. Fig. 1 illustrates the dimensions of the pressure vessel, which will be (L) mm for shell length and (d) mm for inner shell diameter. The design pressure for the necessary volume of liquid to be stored determines the tank's total capacity. 10,000 L of LPG, not to exceed 1.55 MPa maximum pressure, is what is required. The goal of the current study is to evaluate the pressure vessel's structural integrity under pressure loads. Different materials are used for static analysis, and the best material is selected depending on the analysis's findings. The CAD model of the pressure vessel used for the study is shown below.

(i) Material Selection- Three materials are the subject of the study: aluminium 3003, stainless steel 304, and ASTM A357 steel.

For each of the selected materials, the analysis is carried out with static loads. The material's stresses, deformation, and factor of safety are assessed, and the best material is selected for more research based on safety margins, cost, availability, and reliability.

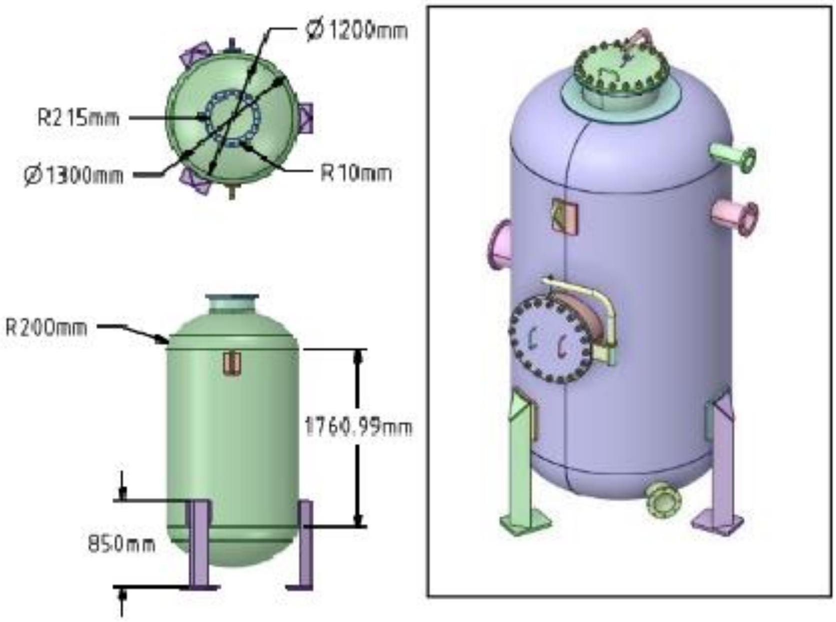

Figure 1- CAD Model of Pressure Vessel

RESULTS AND DISCUSSION

When 1.55 MPa of internal pressure is applied to SS304 steel, the bottom of the pressure vessel exhibits equivalent stress of 82.7 MPa.

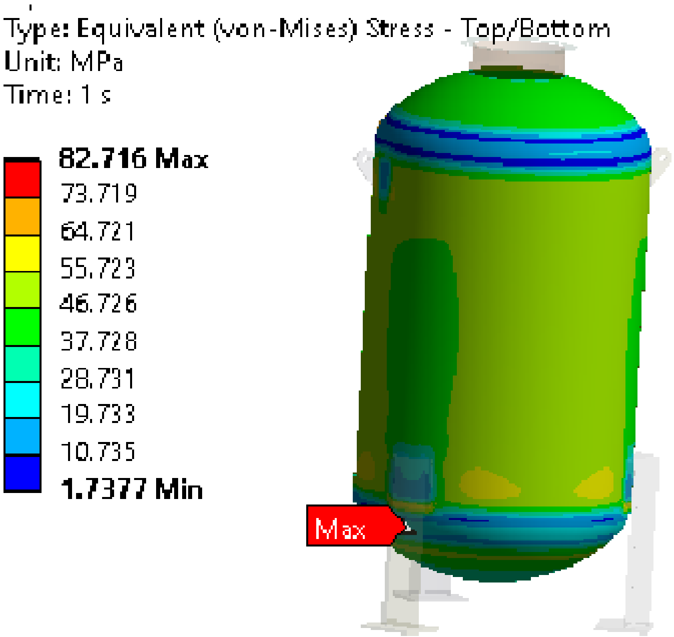

Figure 2- Equivalent stress- SS304 Material

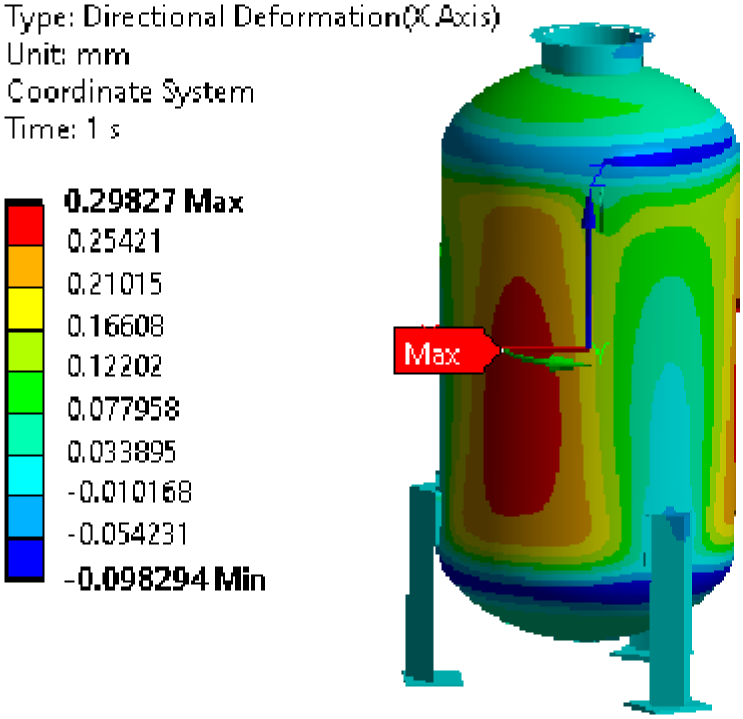

Figure 3- Radial deformation – SS304 Material

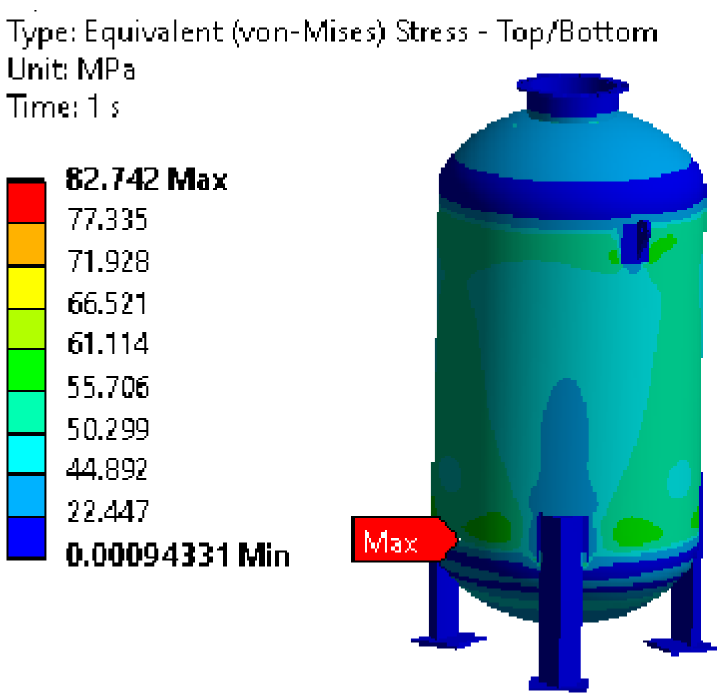

Figure 4- Equivalent stress- ASTM A357

The pressure vessel's produced stresses are less than the material's permitted yield strength. When 1.55 MPa of internal pressure is applied to the SS 304 steel material, a radial deformation of 0.298 mm is seen at the pressure vessel's centre. When 1.55 MPa of internal pressure is applied to ASTM A357 steel material, the bottom of the pressure vessel exhibits equivalent stress of 82.7 MPa. The pressure vessel's produced stresses are less than the material's permitted yield strength. When 1.55 MPa of internal pressure is applied to the ASTM A357 steel material, a radial deformation of 0.287 mm is seen at the pressure vessel's centre. When an internal pressure of 1.55 MPa is applied to Aluminium 3003 material, the bottom of the pressure vessel exhibits an equivalent stress of 81.6 MPa. The pressure vessel's produced stresses are less than the material's permitted yield strength.

CONCLUSION

It gives details on a range of topics that aid in understanding the variables influencing pressure vessel design, manufacture, and analysis. The use of composites in the development of pressure vessels has been examined, along with other factors including material selection. Pre-stressing techniques and the use of composites can result in the creation of lightweight, high-pressure containers for crucial applications. Design elements like head choice contribute to uniform load distribution and stress reduction. Pressure vessel manufacture relies heavily on welding, which is why it's necessary to research potential stress concentrations and failure sites. Nozzles and other openings should be carefully designed because they also serve as stress concentrators and can lead to leaks or failure. For high pressure vessels, optimisation of opening size, position, and configuration is advised. Numerous software programmes and finite element techniques are available for doing accurate fatigue analyses of the vessels for failure during the design phase. A few examples are Caesor, ABAQUS, ANSYS, etc. Software like PV Elite, which produces accurate findings that meet requirements, is a big aid in reducing design time and expense.

REFERENCES

[1] Andrianov, A.; Tomita, E.K.; Veras, C.A.G.; Telles, B. A Low-Cost Filament Winding Technology for University Laboratories and Startups. Polymers 2022, 14, 1066.
[2] Li, G.; Yan, Z.; Outer, B.; Creep, R.; Load, G. Model assessment of the lifetime of a composite overwrapped pressure vessel under creep conditions. J. Phys. Conf. Ser. 2020, 1666, 012069.
[3] Thesken, J.C.; Palko, J.L.; Eldridge, J.; Sutter, J. A Theoretical Investigation of Composite Overwrapped Pressure Vessel (COPV) Mechanics Applied to NASA Full Scale Tests; NASA Center for Aero Space Information (CASI): Hanover, MD, USA, 2009.
[4] Schonberg, W.P. A rupture limit equation for pre-loaded laminated composite plates. J. Compos. Sci. 2018, 2, 3.
[5] Sofi, T.; Neunkirchen, S.; Schledjewski, R. Advanced manufacturing: Polymer & Composites Science Path calculation, technology and opportunities in dry fiber winding: A review. Adv. Manuf. Polym. Compos. Sci. 2018, 4, 57–72.
[6] Regassa, Y.; Lemu, H.G.; Sirhabizu, B. Burst strength analysis of composite overwrapped pressure vessel using finite element method. IOP Conf. Ser. Mater. Sci. Eng. 2021, 1201, 012029.
[7] Forth, S.C.; Pat, B. Composite Overwrapped Pressure Vessels, a Primer; NASA Center for Aero Space Information: Hanover, MD, USA, 2011.
[8] Azeem, M.; Haji, H.; Kumar, M. Application of filament winding technology in composite pressure vessels and challenges: A Review. J. Energy Storage 2022, 49, 103468.
[9] Jois, K.C.; Welsh, M.; Gries, T.; Sackmann, J. Numerical analysis of filament wound cylindrical composite pressure vessels accounting for variable dome contour. J. Compos. Sci. 2021, 5, 56.
[10] Alam, S.; Yandek, G.R.; Lee, R.C.; Mabry, J.M. Design and development of a filament wound composite overwrapped pressure vessel. Compos. Part C 2020, 2, 100045.
[11] Hastie, J.C.; Kashtalyan, M.; Guz, I.A. Analysis of filament-wound sandwich pipe under combined internal pressure and thermal load considering restrained and closed ends. Int. J. Press. Vessel. Pip. 2021, 191, 104350.
[12] Madhavi, M.; Rao, K.V.J.; Rao, K.N. Design and analysis of filament wound composite pressure vessel with integrated-end domes. Def. Sci. J. 2009, 59, 73–81.
[13] Barthelemy, H.; Weber, M.; Barbier, F. Hydrogen storage: Recent improvements and industrial perspectives. Int. J. Hydrogen Energy 2017, 42, 7254–7262.
[14] Sahami, M.; Heidary, H. Parametric study on drilling of GFRP composite pipe produced by fi lament winding process in different backup condition. Compos. Struct. 2020, 243, 111661.

[15] Trzepieciński, T.; Najm, S.M.; Sbayti, M.; Belhadjsalah, H.; Szpunar, M.; Lemu, H.G. New advances and future possibilities in forming technology of hybrid metal–polymer composites used in aerospace Applications. J. Compos. Sci. 2021, 5, 217.
[16] R. Carbonari, P. Munoz-Rojas, E. Andrade, G. Paulino, K. Nishimoto, E. Silva, "Design of pressure vessels using shape optimization: An integrated approach", International Journal of Pressure Vessels and Piping, Volume 88, May 2011, Page no.198-212.
[17] V.N. Skopinskyand A.B. Smetankin, "Modelling and Stress analysis of nozzle connections in Ellipsoidal heads of Pressure vessels under External loading" International Journal of Applied Mechanics and Engineering, 2006, vol.11, No.4, Page no. 965-979.
[18] DrazanKozak, FranjoMatejicek, DarkoDamjanovic, "Weld misalignment influence on structural integrity of Cylindrical Pressure Vessel", Structural integrity and life, Vol. 10, No 2 ,2010, Page no. 153-159.
[19] Vince Adams and Abraham Askenazi, Building better products with finite element analysis, 1st edition, Onward press, USA, 1999.
[20] Noraziah Wahi, Amran Ayob and MohdkabashiElbasheer, "Effect of Autofrettage on Allowable Pressure of Thick- Walled Cylinders", International Conference on Environment and Agriculture Engineering IPCBEE vol. 15 (2011), Singapore, Page no.14-17.
[21] R. Adibi-Asl, P. Livieri, "Analytical Approach in Autofrettaged Spherical Pressure Vessels Considering the Bauschinger Effect", Journal of Pressure Vessel Technology, Vol. 129, August 2007, Page no. 411-418.