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"Analysis of Pressure Vessel for a Storage Application using FEA: Literature Review"

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Abstract**-- The current review examines the design and analysis of a pressure vessel used for storage. Pressure and temperature, as well as material selection, are all elements that influence the construction of a pressure vessel. The use of pressure vessels is quickly increasing around the world. In the chemical, petroleum, petrochemical, and nuclear industries, pressure vessels and holding tanks are required to keep fuel stored. The response, division, and storage of raw material all fall under the heading of apparatus.**

The objectives of this paper are to compare fibrous materials to other materials based on structural and thermal load applications using previous research.

Keywords**-- Pressure Vessels, Pressure Vessels Manufacturing Materials, Theories of Failure, CAD Analysis, ANSYS etc.**

I. INTRODUCTION

Engineering design is a task that ensures a person's readiness for service. This largely covers strength issues in the context of pressure vessel design. The concept of "total design" has far-reaching implications. Aspects of fuel system design, reactor design, or thermal hydraulic design may be included. The underlying theory, decisions, and calculations linked simply to the strength design are referred to as "pressure vessel design" in our later discussions. Heat transfer and fluid flow needs may still drive early design for certain pressure vessels and related equipment.

We will not go into detail about the element of thermal hydraulic design that is intricately tied to structural design, especially for thermal transient loadings. The temperature distribution associated with a specific thermal transient will be presumed to have been examined in a typical design application. However, the designer must still examine how the required vessel combinations will be created from a structural aspect, as well as how these designs will execute their intended function.

The fields of structural mechanics and material science both play key roles in the design of pressure vessels. As previously stated, we attempt to present a description of pressure vessel components in terms of mathematical models that may be solved numerically as well as closed form solutions. The introduction of computer methods (also known as computer-aided design, or CAD) has had a significant impact on pressure vessel component stress and deflection analysis. By combining postprocessing of the answers with visual depiction of numerical findings, their application has been extended to incorporate the assessment criteria as well. In some circumstances, sophisticated software systems are specialized to provide animation, which aids in the visualization and subsequent appreciation of the study.

There have been a variety of design and analysis codes developed that go from conceptual design to analysis, occasionally representing nonlinear geometric and material behavior. Temperatures, deflections, and stresses are commonly recorded, but the study frequently expands to include creep, fatigue, and fracture mechanics analyses. It is now possible to ensure the integrity of designs by capturing changes anywhere in the product development process and updating the model and all engineering deliverables automatically, thanks to the advent of three-dimensional CAD software and their parametric, feature-driven automated design technology.

The vessel's load is determined by parameters such as design pressure, design temperature, mechanical loads (due to dead weight and piping thermal expansion), and assumed transients (usually owing to temperature and pressure) that are expected during the plant's lifetime. The fluid temperature and pressure excursions of the equipment's mode of operation are often reflected in these transients. Of course, the sort of fluid that will be enclosed in the pressure vessel is a critical design parameter, particularly if it is radioactive or hazardous.

Also included is information on the location of the site, which might provide loads owing to earthquakes (seismic), as well as other hypothetical disaster loads.

II. STRUCTURAL AND MATERIAL CONSIDERATIONS

Pressure vessels must be able to tolerate extreme pressure, temperature, and other environmental conditions in order to be used for power production, nuclear or chemical processes, industrial processing, and storage. Corrosion, neutron irradiation, hydrogen embrittlement, and other environmental factors are examples. Pressure vessels must be able to function at temperatures ranging from 600°C to –20°C, with design pressures of up to 140 MPa. Some vessels are made to transport noncorrosive fluids, whereas others are made to survive extreme corrosive and radioactive environments. The type of service, whether continuous or cyclic, might also differ significantly. The pressure vessel material may be required to have certain qualities for each set of operating settings. For example, materials with high notch toughness are required for operation at extremely low temperatures, while materials with high creep strength are required for operation at very high temperatures. Aside from mechanical qualities, the selection process must take into account factors like as manufacturability, commercial availability, and cost. The materials utilized in the building of pressure vessels are:

Steels

- Nonferrous materials such as aluminum and copper.
- Specialty metals such as titanium and zirconium.
- Nonmetallic materials, such as, plastic, composites and concrete.
- Metallic and nonmetallic protective coatings.

The mechanical properties that generally are of interest are:

- Yield strength
- Ultimate strength
- Reduction of area (a measure of ductility)
- Fracture toughness
- Resistance to corrosion

Modes of failure

Two basic modes of failure are assumed for the design of pressure vessels. These are:

(a) elastic failure, governed by the theory of elasticity; and
(b) plastic failure, governed by the theory of plasticity.

Except for thick-walled pressure vessels, elastic failure is assumed. When the material is stretched beyond the elastic limit, excessive plastic deformation or rupture is expected. The relevant material properties are the yield strength and ultimate strength. In real vessels we have a multiaxial stress situation, where the failure is not governed by the individual components of stress but by some combination of all stress components.

Theories of failure

The most commonly used theories of failure are:

(i) Maximum principal stress theory
(ii) Maximum shear stress theory
(iii) Maximum distortion energy theory

Failure occurs when one of the three major stresses approaches the elastic limit, as measured by a uniaxial tension test, according to the maximum principal stress theory. This theory holds true in the case of brittle fractures.

The maximum shear stress equals the shear stress at the elastic limit as measured by the uniaxial tension test, according to the maximum shear stress theory. The maximum shear stress is equal to half of the difference between the biggest (σ_1) and smallest (σ_3) main stresses in this case. This is also known as the Tresca criterion, according to which surrendering occurs when

$$\frac{(\sigma1-\sigma3)}{2} = \frac{+}{\,}\frac{\sigma y}{2} \qquad \text{........................}(1.1)$$

$$\frac{1}{\sqrt{2}}\ [(\,\sigma1-\sigma2)^2+(\,\sigma2-\sigma3)^2+(\,\sigma3-\sigma1)^2] = \ +\sigma y \qquad \text{.....................}\ (1.2)$$

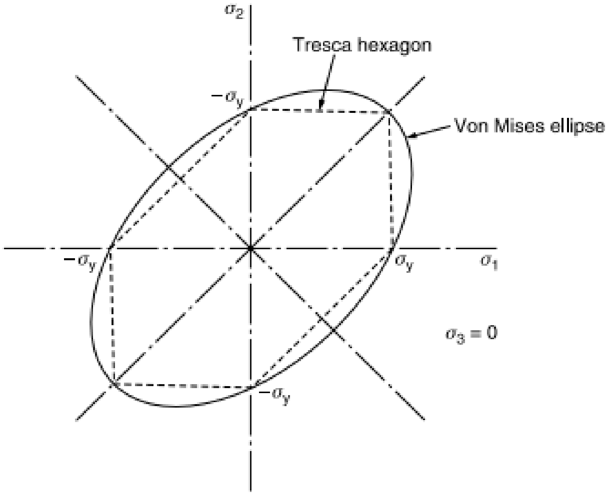

Figure 1.1 Tresca and von Mises theories of failure.

- **Maximum Stress Theory**
- **Maximum-Shear-Stress**

III. LITERATURE REVIEW

There is a long history of Innovative and near-innovative efforts to increase the performance and versatility of spherical and cylindrical pressure vessels have a lengthy history. Some of them are as follows:

The baseline design of a 34,000-tonne subsea shuttle tanker is presented by ***Yucong Ma et al. (2021).*** (SST). For the conveyance of liquid carbon dioxide (CO_2) from current offshore/land facilities to marginal subsea fields, the SST is offered as an alternative to subsea pipelines and surface tankers. Unlike surface tanker operations, which are heavily weather-dependent, the SST can operate in any situation underwater. The SST is a 164-meter-long and 17-meter-wide autonomous underwater vehicle propelled by electricity. For optimal energy efficiency, it travels at a slow speed of 6 knots at a constant water depth of 70 metres and offloads CO_2 via a linked coupling to a subsea well where CO_2 is directly injected. The SST has a high payload of 50 percent displacement, which necessitates a low structural weight design to be economically viable. This is accomplished by designing the SST with a double hull and active pressure compensating devices to deal with the huge collapse pressure loads encountered underwater.

The design and strength of prismatic pressure vessels with innovative geometries for usage as fuel tanks in LNG-fueled ships were investigated in a study presented by ***Younseok Choi et al. (2020).***

The plate-stiffened prismatic pressure vessel had a rectangular cross-section, unlike the traditional cylindrical pressure vessel, and its structure could withstand a standing load thanks to the use of a plate inside. An LNG fuel tank aboard an LNG-fueled crude oil tanker was studied in detail. Strength analysis at the design pressure and test vapour pressure were used to assess the design feasibility of the plate-stiffened prismatic pressure vessel. In addition, evaluations of ultimate strength, dynamic acceleration, buckling, and thermal/fatigue were performed. According to the design standards, a plate-stiffened prismatic pressure vessel might be utilized as a fuel tank in LNG-fueled ships as a consequence of the assessments.

Shahrzad Daghighia et al. (2020) introduced a series of so-called super ellipsoids of revolution that are meant to have bend-free states under uniform internal pressure. When compared to traditional geometries, super ellipsoids of revolution provide various advantages, including improved packing efficiency, smoother stress flow fluctuation, reduced stress concentrations, and lower assembly costs. In this paper, a novel generalized set of governing equations is devised and solved analytically to depict bend-free states in composite super ellipsoids of revolutions. To achieve bend-free states, stiffness tailoring using tow steering is used. To discover the needed distribution of fiber orientations, a parametric investigation is done on different super ellipsoids of revolution. Finite element modelling is used to verify the analytical solution, and the results are compared to an isotropic baseline.

Using stiffness tailoring, super ellipsoids of revolution under uniform internal pressure are constructed to have bend-free states. A super ellipsoid of revolution can be considered a more realistic baseline design for many structural applications such as blended wing body aero planes, pressure vessels, and underwater constructions, which is why this choice was made.

Nebe et al. (2020) explore the effects of stacking sequence on laminate quality, structural deformation, and eventually burst pressure in composite pressure vessels. As a result, a known laminate is investigated using a subscale vessel geometry and varying stacking sequences. The specimens are pressed to burst pressures of 166.11 MPa in a specially built chamber. The deformation is tracked up to burst utilizing 3D digital picture correlation employing a multi-sensor setup of stereometric devices. The experimental results demonstrate that the analyzed stacking sequences had a 67 percent difference in burst pressure. The conclusions of 3D elasticity theory are compared to experimental cylinder strains and burst pressures.

As a result, the findings highlight the importance of employing analytical and numerical analysis methodologies that account for transition-related effects between the cylinder and dome.

The hydrostatic test was used to test a pressure vessel under simulated service pressure. During the hydrostatic test presented by ***Noraphaiphipaksa et al. (2020),*** failures from plastic deformation of the cover frame and water leakage were noted (2020). The main cause of these problems was investigated using finite element analysis (FEA). Due to inappropriate geometries and positions of apertures, reinforced pad, and sight ports, the stresses on the cover frame were discovered to be higher than the material's restrictions (i.e., SUS316 stainless steel). As a result, FEA was used to develop and analyse a new pressure vessel with obround apertures, shorter and thicker sight ports, and a larger reinforced pad. After the hydrostatic test, no water leakage or failure was discovered in any of the new pressure vessel's components.

Carbon dioxide (CO_2) vessel leakage can have a substantial impact on the safety of carbon capture and storage systems (CCS). Small rupture leakage in the early stages of an accidental discharge must be studied.

An experimental CO_2 blowdown device was provided, transient pressure and mass flow rate were recorded and calculated, and a pressure vessel release model was created in this study presented by ***Wang Yanglea (2019)*** to evaluate the release from minor rupture under different operating conditions. In addition, the phase distribution in the vessel was studied using a homogeneous model and a phase separation model. According to the results of the experiments, the phase separation model is more applicable to small-scale rupture leakage. The influence of beginning pressure on pressure release is minimal, while the influence of initial temperature and nozzle placement on pressure release is substantial.

The goal of this research is to look at the CO_2 transient process in pressure vessels and come up with a theoretical model to represent it during the early stages of leaking. Simultaneously, the impact of various initial thermal and geometric parameters on the early decompression process was investigated, assisting in the understanding of CO_2 parameter variation behavior in the upstream and improving mass flow rate and downstream diffusion process prediction accuracy.

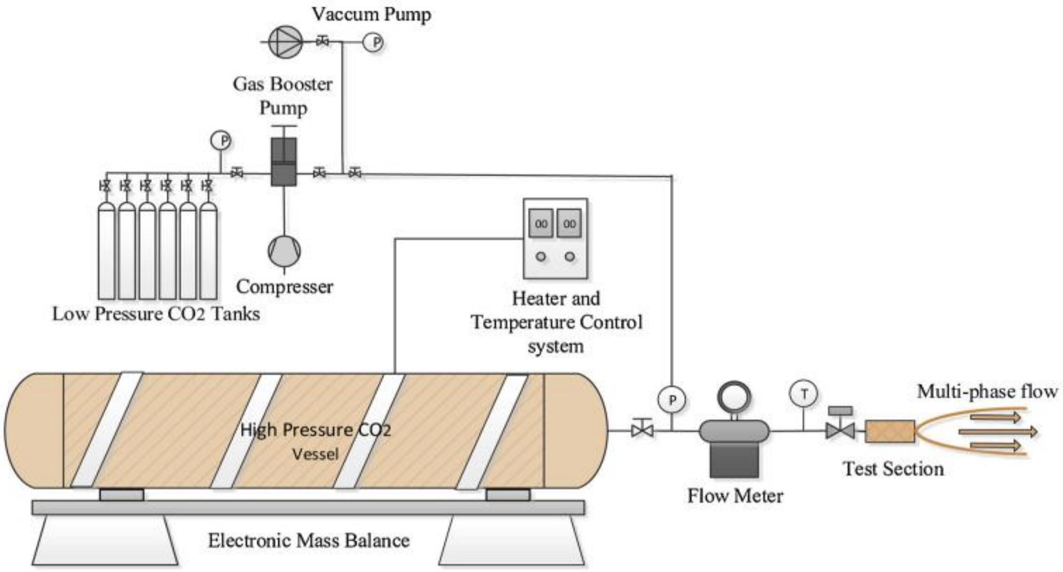

Figure 2.1 CO_2 blowdown device. Reported on Wang Yanglea et. al. (2019)

Mahesh Kadam and colleagues (2019) used finite element analysis to forecast the static burst pressure in closed thick-walled unflawed cylinders (FEA). The analysis takes into account the cylinder's failure due to a ductile fracture mode. Different diameter ratios (K=outer diameter/inner diameter, ranging from 1.5 to 6) of thick-walled cylinders were examined. The implicit elastoplastic analysis of the cylinders was performed using the commercially available ANSYS FEA code, which took into account geometric and material nonlinearities. The Arclength algorithm, which is included in the ANSYS code, was used to solve the solution convergence difficulty caused by tangent singularity in the limit state. Over the examined range of diameter ratios, i.e., K=1.5 to 6, the FEA predicted static burst pressure for thick-walled cylinders, which demonstrated good agreement with the Svensson burst model. The use of an elastic-perfectly plastic model to forecast static burst pressure has implications.

Cold stretching is a key lightweight method for lowering the cost of cryogenic tanks, which are commonly used to store liquefied gas. Under external pressure, ***Zekun Zhanga et al. (2018)*** investigated the effect of cold-stretching on the buckling behavior of cylindrical vessels with varying initial out-of-roundness. Experiments were used to determine the buckling pressures, stresses, and buckling modes of cylindrical vessels. The intricate geometry of the vessels before and after cold stretching was obtained using a 3D laser scanner. Out-of-roundness, thickness, diameter, and yield strength are all considered when discussing the impacts of cold-stretching on buckling. For starters, in our instance, buckling of cylindrical vessels is elastic buckling, hence yield strength has no bearing on buckling pressure. Second, in our circumstance, the detrimental effect of raising the diameter thickness ratio was found to be minor (within 3.3 percent). Finally, because out-of-roundness decreased after cold-stretching, buckling pressure increased.

The methodology presented by ***Jaemin Lee et al. (2018)*** for determining the minimum design vapor pressure of prismatic pressure vessels for on-ship application is described. The codes for a novel concept design, such as a prismatic pressure vessel, are guided by engineering authority utilizing a design by analysis method (DBA). Because DBA approaches directly calculate the loads, they eliminate the inherent conservativeness that exists in a design by rule (DBR). A case study was used to demonstrate the proposed method's technique.

An FEA was also carried out for the purpose of verification. The findings show that without doing an iterative FEA, the suggested technique can accurately estimate the needed minimum shell thickness and specified vapour pressure. Furthermore, because the suggested technique directly estimates the crack propagation rate to minimize an extra margin while satisfying the fatigue crack propagation criterion, tank shell thickness can be reduced.

The goal of B.B. Liaoa's (2018) study was to investigate the dynamic structural reactions and failure processes of composite pressure vessels subjected to low velocity impact. Puck's failure criteria and strain-based damage evolution rules for fiber and matrix are applied in a three-dimensional laminated media model based on sub-laminate theory for intralaminar damage. By employing this method, the impact responses of composite pressure vessels may be computed based on sub-laminates, and fiber and matrix damage can be anticipated based on each ply. Second, the suggested laminated media model is implemented utilizing the time stepping technique and the bilinear cohesive model to simulate interlaminar delamination in ABAQUS/Explicit user-defined material subroutine VUMAT. Finally, numerical simulations are used to investigate the impact force-time/central displacement curves, as well as intralaminar and interlaminar damage and delamination features for composite pressure vessels, at three different impact energies.

Tomoki Takamia et al. (2018) developed and verified a simulation method for forecasting global and local hydro elastic response of a ship that links CFD and FEA. The efficiency of the CFD-FEA coupling approach is proven by comparing the prediction with linear/ nonlinear strip method, 3D panel method, and towing tank test results under various wave circumstances in terms of rigid body kinematics and slamming impact pressure. The CFD-FEA coupling method's hydro elastic behavior, known as the whipping moment, is further validated by comparing it to nonlinear strip method, 3D panel method, and tank test findings. Finally, the proposed approach is tested on a realistic large container ship structure that is subjected to heavy waves. The structural behavior of a double bottom structure under global and local bending moments is studied.

At ***Vincent Mendeza et al. 2018***, the relevance of aneurysmal wall elasticity in determining clinically important parameters such as the wall shear stress (WSS) is discussed, as well as the importance of using realistic boundary conditions to account for aortic stretch and twist transmitted by heart motion.

Finite element analysis (FEA) and computational fluid dynamics (CFD) results were compared to 2-way fluid-solid interaction analyses (FSI), which were performed on ATAAs with either bicuspid or tricuspid aortic valves (TAV). Because there is no gold-standard for assessing the hemodynamic and structural mechanics of ATAAs, and because our approach has limitations, the computational technique must be validated before being used in ordinary clinical practise, as proven in this study.

Puneet Deolia et al. (2016) apply a finite element method to forecast burst pressure using the Ramberg-Osgood equation. These findings were compared to those obtained using the elastoplastic curve and the real stress strain curve. Experimental data taken from the available literature was used to validate the results obtained by finite element analysis. The pressure at which a vessel bursts/cracks and internal fluid spills is known as burst pressure. In the chemical, medical, and aviation industries, a precise prediction of burst pressure is required. The design safety limit for burst pressure should not be exceeded. If this pressure is surpassed, a mechanical rupture may occur, resulting in a permanent loss of pressure containment. As a result, for all essential applications, a burst pressure calculation is required. A material curve is required to compute burst pressure numerically. There are several material models that are used to define material curves, with Ramberg-Osgood being one of the most prevalent.

Mosayeb et al. (2014) offered an analytical solution for the calculation of time-dependent creep stresses and displacements of homogeneous thick-walled cylindrical pressure vessels, assuming that Norton's law governs thermo-creep response of the material. The solutions of the stresses at a time equal to zero (i.e., the initial stress state) are required for the stress analysis in a homogenous pressure vessel with material creep behavior. This is the answer for materials that have a linear elastic characteristic. As a result, a differential equation for displacement is obtained using equations of equilibrium, stress strain, and strain-displacement, and the stresses at a time equal to zero are determined.

V. Chaudhry et al. (2014) demonstrate the structural integrity of a reactor pressure vessel; nevertheless, a full stress analysis must be performed, accounting for transients throughout various reactor operating situations. During operating transients in thick-wall reactor pressure vessels, the temperature gradient across the vessel thickness is time-dependent, which complicates predicting the stress field across the vessel wall thickness. A complete thermal stress study, taking into account time-dependent fluctuations, should be included in the design of such thick vessels.

M. Jeyakumar and T. Christopher (2013) performed a finite element analysis (FEA) on a cylindrical pressure vessel built of ASTM A36 carbon steel with weld-induced residual stresses using the ANSYS software package and a 2D axisymmetric model. To determine the effect of residual stresses on failure pressure, an elasto-plastic analysis was conducted first to determine the failure pressure of a pressure vessel without residual stresses. The residual stresses created in the pressure vessel during welding were then assessed using a thermo-mechanical finite element analysis. Finally, another elastoplastic study was conducted to determine the impact of residual stresses on the pressure vessel's failure pressure. Due to adverse residual stresses, the failure pressure is reduced in this analysis.

Both numerical and experimental approaches must be used when designing safe, ergonomic, and cost-effective ships or vessels, according to ***Ahmet H. Ertasa et al. (2013).*** Large-scale structural modelling, such as that seen in ships, often employs Finite Element Analysis (FEA) techniques. It is feasible to strengthen the strength of a mercantile vessel onboard by using Finite Element Methods (FEM) in the realm of Computer Aided Design (CAD) engineering. As a result, using the ANSYS package programmed, the strength of a commercial vessel onboard was tested under working conditions in this study. The findings of this study provide designers with some guidance for building mercantile vessel shipboards.

The behaviour of a pressure vessel liner during burst pressure testing is investigated by ***E.S. Barboza Neto et al (2011).*** A polymer blend of 95 percent low linear density polyethylene (LLDPE) and 5 percent high density polyethylene (HDPE) was used to create the liner (HDPE). The liner will be utilized in an all-carbon/epoxy compressed natural gas (CNG) shell with variable composite thickness, which will be created using the filament winding technique. On a smaller scale and with genuine liner models, hydrostatic tests were done. Using commercial Finite Element Analysis (FEA) software, the Tsai-Wu and von Mises criteria were used to design and predict the failure of the composite laminate shell and the polymeric liner, respectively. To determine suitable production parameters for the polymeric liner so that it could be used successfully in a composite pressure vessel, simulation and testing were both necessary.

Pablo Vinicius Bassani et al. (2009) investigate the collapse of a pressure vessel during a Hydrostatic Test. For a crack-like fault in the location where the failure occurred, this study will use ASME code Section VIII and API 579 Fitness-For-Service examination. Failure Assessment Diagram determines the acceptability of the harm (FAD). According to the research, a crack-like fault in the cylindrical shell of this pressure vessel would have to be very large to cause brittle fracture without leaking, indicating that the collapse was not caused by this type of damage.

B.S. Azzam and colleagues (1996) suggested a new design technique that allows for quick and efficient design computations. This method allows the composite pressure vessel designer to quickly determine the ultimate failure pressure of these vessels based on the number of reinforced layers, layer thickness, fiber orientations, and materials used. In this project, a variety of metal tubes were wrapped in a variety of composite layers constructed from various fibrous materials (glass, graphite and Kevlar fibers). The tubes were then utilized as pressure vessels, which were tested until they exploded. The findings of the experimental testing were compared to the theoretically proposed design for these composite pressure vessels. The theoretical and experimental analyses were found to be in good agreement in this comparison.

IV. CONCLUSION

In the present review, a pressure vessel currently employed for various operation like transportation, storing the high temperature liquid is studied. Following observations are made during the review studies:

- Experimental analysis should be carried out for further research.
- A variety of fiber resins should be investigated.
- While examining a single material, more parameters can be considered.
- Different pressure vessel designs could be considered for future research

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