A Review on Optimization of Finite Element Modelling for Structural Analysis of Pressure Vessel

Aniket A. Kulkarni[1], Keshav H. Jatkar[2]

Student[1] and Professor[2], Mechanical Engineering Department, Walchand Institute of Technology, Solapur University, Maharashtra, India.

***Abstract:* - It is important for every engineer to analyze and design the pressure vessel that will provide safety, durability and serviceability to the company. Accomplishing this task will require knowledge of parameters that affecting the pressure vessel due to varying loads, pressure and thickness of shell element. The most important one is that the given geometry of pressure vessel must be analyzed to assure it meet the design standards and design of pressure vessel is required to meet an acceptable stresses. For more than two decades, the finite element method has been the most effective numerical tool for the analysis of solids and structures. The method however can only provide approximate solutions to a given mathematical model of a physical problem. A structural analysis can be understand more theoretically as a method of engineering design process to prove the serviceability and safety of a design without a dependence on directly testing it. Considering this theory, the present paper focuses on a review of a structural analysis and optimization of pressure vessel to identify the existing work made in the analysis of pressure vessel and to form a theoretical foundation for understanding the recent developments, then to gain some insight into which domains are relevant in order to position the research.**

Keywords: **- Pressure vessel, structural analysis of pressure vessel, optimization.**

I. INTRODUCTION

A pressure vessel is a closed container designed to hold gases or liquids at a pressure substantially different from the ambient pressure. The pressure differential is dangerous and many fatal accidents have occurred in the history of pressure vessel development and operation. Consequently, pressure vessel design, manufacture, and operation are regulated by engineering authorities backed by legislation. For these reasons, the definition of a pressure vessel varies from country to country, but involves parameters such as maximum safe operating pressure and temperature.

Pressure vessels are leak proof containers. They may be of any shape and range from beverage bottles to the sophisticated ones encountered in engineering applications. The ever increasing use of pressure vessels for storage, industrial processing and power generation under unusual conditions of pressure, temperature and environmental has given special emphasis to analytical and experimental methods for determining their operating stresses.

Pressure vessels are designed to operate safely at a specific pressure and temperature technically referred to as the "Design Pressure" and "Design Temperature". A vessel that is inadequately designed to handle a high pressure constitutes a very significant safety hazard. Because of that, the design and certification of pressure vessels is governed by design codes such as the ASME Boiler and Pressure Vessel Code in North America, the American Society of Mechanical Engineers appointed a committee to develop a boiler code in 1911. The objective of the ASME Boiler & Pressure Vessel Code is the same today as it was in 1911. The objective is to provide rules defining the minimum requirements to assure that boilers and pressure vessels are constructed in a manner that they may be safely operated. Section VIII, Division 1 of the ASME Boiler & Pressure Vessel Code provides rules for the construction of pressure vessels. Since the ASME Code is a "safety" code, it is not a purchase specification that defines all the criteria that are required for specific applications. This becomes clear when it is recognized that Section VIII, Division 1, is written to cover a wide range of industrial and commercial pressure vessel applications. [1]

II. LITERATURE REVIEW

Following work consists of literature survey, summarizing the published work on characterization of Pressure vessel and application of the pressure vessel in industry. Regarding literature survey covers the study of finite elements characteristics, elements and their finite element technique have been discussed briefly in it. Based on literature review it is observed that traditionally pressure vessel studies are centred on finite element methods. But there are few studies which includes structural design of pressure vessel. Following section reviews literature in the same area of pressure vessel.

According to the Ming-Hsien Lu et.al [2] if a simplified 2-D axisymmetric model is used to simulate the stress behaviour of the nozzle-vessel structure, the actual vessel radius can be directly used, which could obtain a conservative membrane and membrane plus bending stress intensities in the nozzle vessel junction section. This simplified 2-D model could also predict conservative membrane stress intensity at the nozzle-to-pipe connection location; this paper creates three different 2-D axi-symmetric finite element models, where different vessel radii are modelled, i.e. 1, 1.5 and 2 times the actual vessel radius. Using these simplified numerical models to calculate the membrane and membrane plus bending stress intensities along some selected sections when undergoing internal pressure loading, and comparing these results with those evaluated from the realistic 3-D model, it shows that the 2-D model with vessel radius equalling to the actual value could well represent the behaviour of a nozzle attached to the vessel.

This paper presents the analysis results of stress distributions in a horizontal pressure vessel and the saddle supports. A quarter of the pressure vessel is modelled with realistic details of saddle supports. And the effect of changing the load and various geometric parameters is investigated. Author found the Stress distribution (in MPa) in saddle parts by increasing the load on saddle and recommendations are made for the optimal values of ratio of the distance of support from the end of the vessel to the length of the vessel and ratio of the length of the vessel to the radius of the vessel for minimum stresses both in the pressure vessel and the saddle structure. Shafique M.A. Khan[3]

This paper discusses the scale issues involved. If a fire protection of pressure vessels for transport and storage of dangerous goods is to be considered then organizations are conducting theoretical analysis followed by fire testing of thermal protection systems to determine how long they delay thermally induced failure. In most recent cases the organizations chose to do small scale fire testing because of the obvious cost savings. This paper focuses on to show how identical fire heating conditions can give dramatically different failure times and modes of failure for small and large scale tanks if the conditions are not truly similar. It concludes that small tanks may behave very differently than large tanks in severe fires if the small tanks and the fire conditions are not similar between the two scales. A.M. Birk [4]

Drazan Kozak et.al [5] made numerical analysis on cylindrical pressure vessel with changeable head geometry i.e. semi-elliptical and hemispherical heads with three types of elements: SOLID 95, PLANE 183 and SHELL 181. It is concluded that in both cases of pressure vessel heads, using of PLANE 183 element presents the best approach, because of minimal number of elements for meshing, shortest calculation time, insight into the stress distribution per plate thickness and obtained results which are closest to the analytical ones. This type of axisymmetric element could be recommended in such cases, when the total symmetry of model is considered. Also analysis of cylindrical pressure vessel with different head type is performed in purpose of comparison of values of maximal equivalent stresses. It is concluded that smaller values of equivalent stresses are appearing in pressure vessel with hemispherical heads, and equivalent stress distribution is advantageous too in that case of head geometry.

Dr. Clemens Kaminski [6] made a study on stress analysis on pressure vessel. In this he found out the stresses in cylinder and sphere, failure modes of pressure vessel under bulk yielding and buckling, stress concentration and cracking and also hoop longitudinal and volumetric strain.

Pressure vessels are a commonly used device in marine engineering. Until recently the primary analysis method had been hand calculations and empirical curves. New computer advances have made finite element analysis (FEA) a practical tool in the study of pressure vessels, especially in determining stresses in local areas such as penetrations, O-ring grooves and other areas difficult to analyze by hand. This project set out to explore applicable methods using finite element analysis in pressure vessel analysis. David Heckman [7].

Michael A. Porter [8] made the comparison between linear and nonlinear FE analysis of a typical vessel nozzle. In this paper he presents a nonlinear (elastic-plastic, material nonlinearly only) analysis of the same nozzle and results are compared with the results from the previous linear analysis. He concluded that nonlinear FE may not be necessary for thin wall vessels. And the results using linear FE appear to be suitably conservative.

Pavo Balicevic et.al [9] has chosen a pressure vessel of elliptical head to analyze its strength and he described the method for calculating strength, and also describe the distribution of total circular forces and radial forces of the cylindrical vessel with ellipsoidal heads.

Nidhi Dwivedi and Veerendra Kumar [10] made the analysis on burst pressure prediction of pressure vessel using FEA. He considered the two cases of pressure vessel for analysis - first is pressure vessel with end caps and second one is pressure vessel without end caps. Considering the von mises yield criteria, he analyzed that the relative error between the experimental value and the FEA result in case of the pressure vessel with end caps is much better than the pressure vessel without end caps. Hence he suggested to analyze vessel along with their end caps to obtain better results.

A. Summary of Literature Review

From literature review it is clear that the pressure vessel has evolved over the years. Although it is evolved deeply there is still structural analysis of pressure vessel is not made by varying the parameters like internal pressure and thickness to analyze the different stresses, strain and deformation occurred in pressure vessel and further the thickness optimization of pressure vessel which explains the optimization of finite element analysis of pressure vessel.

B. Findings of the Literature Review

The above mentioned literature can be summarized in the following way:-

1. There are few studies reporting about the work done related to analysis of pressure vessel and its failure modes under bulk yielding and buckling. Further there are very less studies on structural analysis by varying the parameter like internal pressure and thickness of the pressure vessel.
2. Present studies have not identified the effect of thickness optimization of pressure vessel which may govern the percentage of saving of material and reduction in its cost.

III. OBJECTIVES OF RESEARCH WORK

It can be said that the literature do not directly address the optimization of finite element modelling of structural analysis of pressure vessel, thus there is a need of a analysis as well as optimization of the pressure vessel.

Objectives of research work include:

1. Study of literature on finite elements of pressure vessels.
2. Structural design of pressure vessel using FEA is not studied adequately as discussed in proposed work content. Hence, design validation can be carried out using commercial FEA tools such as ANSYS and verifying the results with analytical solution.
3. Optimization of pressure vessel can be done by optimizing its thickness while considering its stress ranges and within its permissible stress limit.
4. Optimum solution can be found out by varying mentioned below parameters.
5. By varying internal pressure (in 05 intervals)
6. By varying thickness. (in 10 intervals)
7. Verify the results with analytical solution.
8. Find out the optimum solution.

IV. CONCLUSIONS

1. Pressure vessel has several functions apart from holding the gas pressure. Also from literatures it appears that pressure vessel can be designed using experimental, analytical and numerical techniques.
2. Solved the case study and compare the results through ANSYS software and theoretically.
3. To achieve the optimal solution on the basis of stress, strain and deformation comparison.

REFERENCES

[1] Pressure Vessel Design, fabrication and test, ASME section VIII, div. 1

[2] Ming-Hsien Lu, Jiun-Shya Yu, Jien-Jong Chen, *The effect of analysis model on the stress intensity calculation for the nozzle attached to pressure vessel under internal pressure loading,* International Journal of Pressure Vessels and Piping 117-118 (2014) 9-16.

[3] Shafique M.A. Khan G, *Stress distributions in a horizontal pressure vessel and the saddle supports,* International Journal of Pressure Vessels and Piping 87 (2010) 239-244.

[4] A.M. Birk G, *Scale considerations for fire testing of pressure vessels used for dangerous goods transportation,* Journal of Loss Prevention in the Process Industries 25 (2012) 623- 630.

[5] Drazan Kozak1, Ivan Samardzic2, Antun Stoic, Zeljko Ivandic, Darko Damjanovic, *Stress Analyses of Cylindrical Vessel with Changeable Head Geometry,* BULETIN ştiinţific, Seria C, Volume XXIII, ISSN 1224-3264.

[6] Dr. Clemejns Kaminski, *Stress Analysis & Pressure Vessels,* University of Cambridge, 2005.

[7] David Heckman, *Finite element analysis of pressure vessels,* MBARI 1998.

[8] Michael A. Porter, Dennis H. Martens, *Comparison of Linear and Nonlinear FE Analysis of a Typical Vessel Nozzle*,199.

[9] Pavo Balicevici et.al, *Strength of Pressure Vessels with Ellipsoidal Heads*, Journal of Mechanical Engineering 54(2008)10, 685-692.

[10] Nidhi Dwivedi and Veerendra Kumar, *Burst pressure Prediction of Pressure Vessel using FEA*, International Journal of Engineering Research & Technology (IJERT), Vol.1 Issue 7, September-2012, ISSN: 2278-0181.