International Journal of Interdisciplinary Innovative Research & Development (IJIIRD)
ISSN: 2456-236X
Vol. 10 Issue 01 | 2025

Design modifications and transient stress analysis of mixing chamber used in chemical industry for dynamic behaviour assessment under varying operational conditions

Satish Purushottam Eandole[1], Nitin A. Kharche[2], Santosh R. Shekokar[3]
[1]PG Student, Department of Mechanical Engineering, Padm. Dr. V. B. Kolte College of Engineering, Malkapur
[2,3]Department of Mechanical Engineering, Padm. Dr. V. B. Kolte College of Engineering, Malkapur
DOI: 10.5281/zenodo.16734761

ABSTRACT

Pressure vessels, integral components in industries such as oil, gas, chemical processing, and power generation, are designed to handle highly toxic and compressible fluids under extreme pressure. With the increasing demand for alternative fuels, the need for high-pressure and high-temperature vessels has escalated, particularly in petroleum refineries and chemical plants. Recent advancements in pressure vessel technology have focused on new-grade materials, composite materials, and welding techniques, with finite element analysis (FEA) playing a pivotal role in understanding fatigue and creep behavior. Mixing chambers, a type of pressure vessel used in chemical industries, experience significant deformation and distortion due to varying pressure and temperature conditions. For instance, additives are introduced at different time intervals, with pressures cycling from 0 to 0.16 MPa and fluid temperatures ranging from 0 to 200°C. This fluctuating environment generates high local stresses that reduce the fatigue life of the mixing chamber, often leading to premature failure. The present study aims to perform transient dynamic stress analysis to identify stresses within the mixing chamber under general time-dependent loads. Additionally, finite element analysis is employed to predict and enhance fatigue life by determining time-varying displacements, strains, and forces acting on the pressure vessel. The study also seeks to modify the existing design provided by the manufacturer, optimize the nozzle angle for improved mixing, and validate the findings through simulation using ANSYS. By addressing these objectives, the research contributes to the development of more resilient mixing chambers, enhancing their longevity and performance under variable operational conditions. These insights are crucial for industries reliant on high-performance pressure vessels, ensuring safety, efficiency, and reliability in their processes.
Keywords: Mixing chambers, Finite element analysis (FEA), Stress analysis

1. INTRODUCTION

Introduction and background

Pressure vessels are containers used to handle fluids which are highly toxic, compressible and works at high pressures. These vessels are applied in numerous industries such as oil, gas, petroleum, beverage, chemical, power generation, food and fertilizer, etc. Pressure vessels are used for various purposes such as nuclear reactor vessels, pneumatic reservoirs and storage vessels of liquefied gases (Lee et al., 2017). From last few decades due to increased demand of alternative fuels generates the need of high pressure and temperature vessels for petroleum refineries and chemical plants. Currently there is much advancement in the pressure vessel field like in case of investigating new grade material, composite materials, welding techniques, etc. The applications of finite element analysis is important for understanding of fatigue and creep process (Raffiee et al., 2018). In some chemical industry mixing of liquid or gaseous chemical take place in enclosed chamber such as pressure vessel hence it is called as mixing chamber. For deeper understanding of stress can be archived by transient dynamic analysis. The transient dynamic analysis is used to determine to determine of structure under the action of any general time dependent loads. It is used to determine the time varying displacements, strains and force of a component by Patil et al. (2016).

2. LITERATURE REVIEW

As per the stated problem the work focused on this area is reviewed with the help of standard journal papers. After studying the literature, it can be observed that some work has been done in the field of mixing chamber as pressure vessel.

A computational method was carried out by Kong et al., (2014) to simulate the starting transient flow of a vacuum ejector system. The vacuum ejector-diffuser system has been widely used in many applications such as refrigeration systems. The starting transient flows of supersonic vacuum ejector-diffuser system, and its performance characteristics were simulated and analyzed by numerical methods. Primary numerical analysis results show that the chevrons get a positive effect on the vacuum ejector performance: less starting time and secondary chamber equilibrium pressure are found in chevron transient flow, compared with the convergent nozzle. A CFD method based on transient scheme has been applied to simulate the equilibrium flows and flow dynamics behavior of the secondary chamber.

Fig -1.1: Details of valve with plug

Alam et al. (2020) focus on the design of filament-wound composite overwrapped pressure vessels, emphasizing their strength-to-weight advantages. Their tests show that these composite vessels withstand pressures up to 300 MPa with minimal deformation, offering a 25% weight reduction compared to traditional metal vessels. The authors find that composite materials provide increased resilience under dynamic loading conditions, with failure strains reduced by 15-20% in optimized composite layers. These results support the use of composites in aerospace and marine applications where weight efficiency is paramount.

Arumugam et al. (2020) analyze corroded pipelines with single defects under internal pressure, using FEA to quantify the impact of corrosion on structural integrity. They find that pipelines with defects of 5 mm depth experience a 30% reduction in burst pressure. For example, pipelines with this level of corrosion failed at around 150 MPa, whereas intact pipelines withstood pressures up to 220 MPa. These results underscore the importance of regular inspections and timely repair in extending pipeline service life.

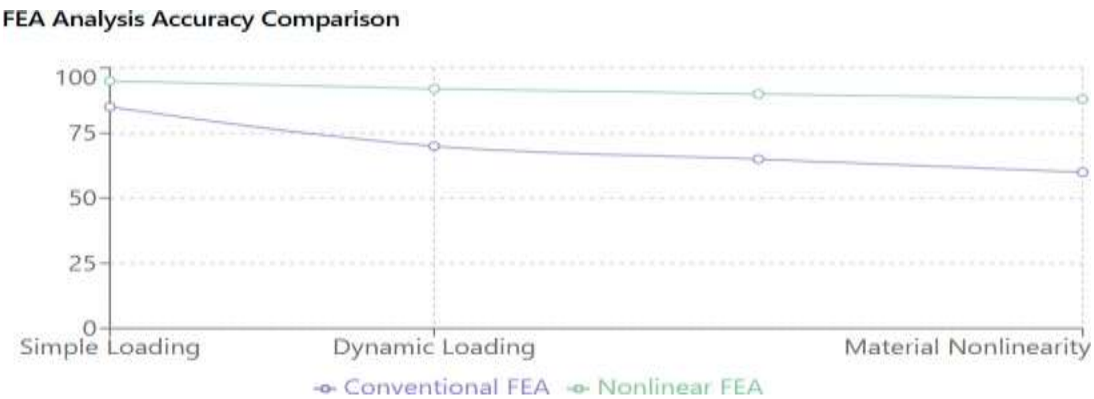

Fig -2.1: FEA analysis accuracy comparison

Failure Prevention Method Distribution: A pie chart shown in Fig. 2.3 illustrating the relative importance of different approaches to failure prevention in pressure vessel design and maintenance.

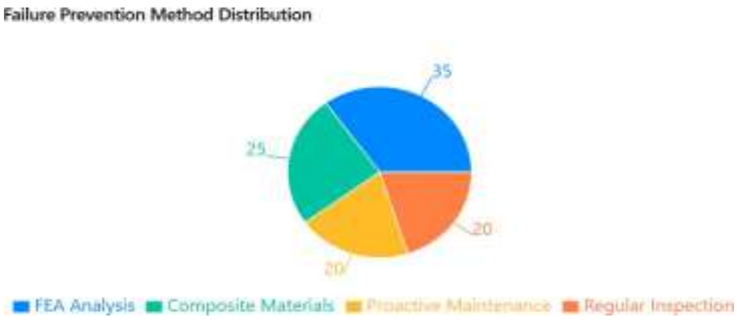

Fig. 2.2 Failure prevention method distribution

3. Finite Element Analysis (FEA)

3.1 CAD Model

Modeling of mixing chamber is done in ANSYS Workbench.17.0 It is a common platform for solving engineering problems. Design modeler is a component of ANSYS workbench.

Sketch mode: It Contains tools to create 2D geometric shapes as a prerequisite to 3D geometry creation or concept modeling.

3D Geometry: Geometry derived from sketch entities such as extrusions, revolves, surface models, etc. Fig. 5.1 shows the model of mixing chamber.

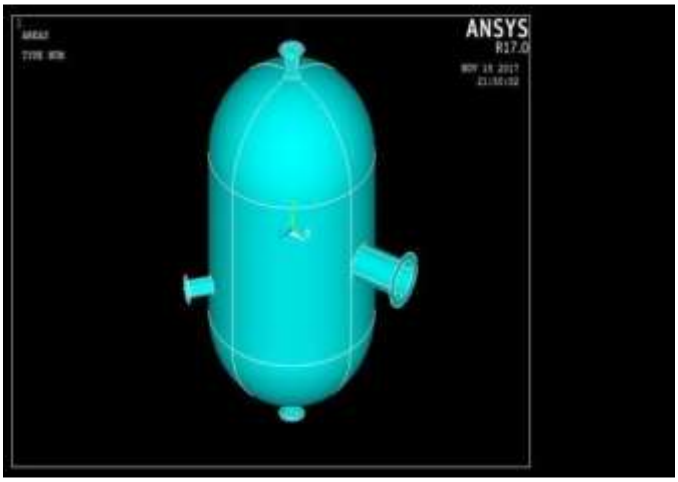

Fig. 3.1 Modeling of mixing chamber Table No. 3.1 Mixing chamber meshing

Element type	Shell93
Mesh	Shell mesh
No. of nodes	145298
No. of elements	48387

3.2 Nozzle position optimization

With the help of conventional design, it in not possible to calculate stresses and deformations at different position of nozzle on the shell periphery. Location of nozzle is not considered in the conventional design process. Mechanical APDL is parametric Design Language (APDL), including parameters, array parameters, macros, and ways to interface with the ANSYS GUI. It explains how to automate common tasks or to build your model in terms of parameters. Initially two input nozzle are 120^0apart from each other on the periphery. According to FEA as the distance between two nozzle changes stresses and deformation generate in the mixing chamber changes. So by fixing two nozzle positions at the periphery of mixing shell varies the one nozzle radially along the mixing shell with 2^0 interval in the opposite plane of fixed nozzle. Calculate the all stresses and deformation in that plane. The following graph shows in Fig.3.2 and Fig.3.3 the minimum stresses and deformation.

1) Deformation at different nozzle angle position
2) Stresses at different nozzle angle position

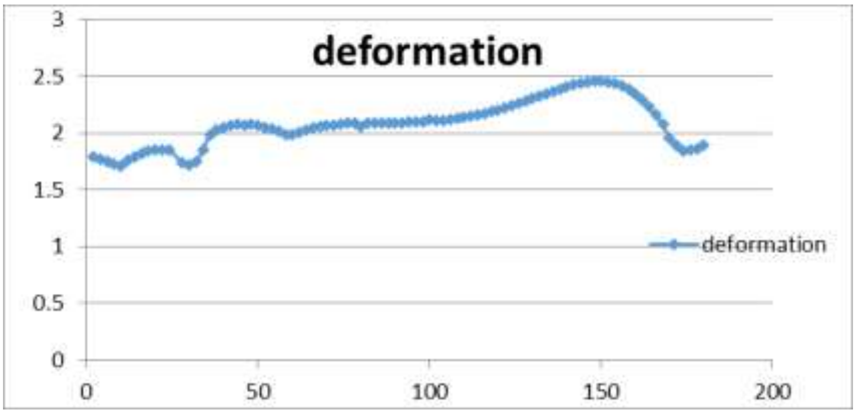

Fig. 3.2 Deformations at different angle position.

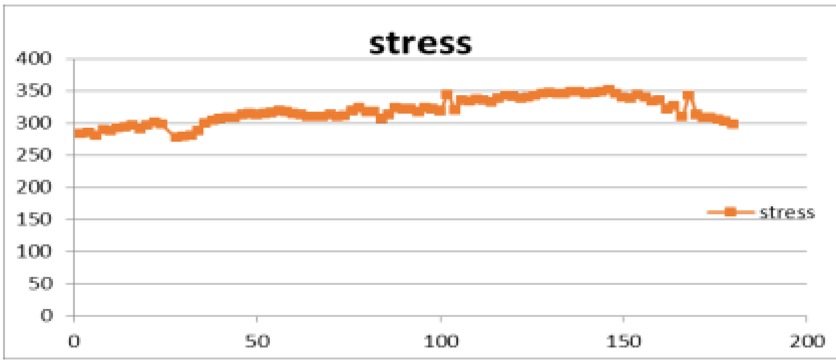

Fig. 3.3 Stress at different angle position.

4. VALIDATION

The experiment is conducted by actual testing of mixing chamber with strain gauge. A strain gauge is a sensor whose resistance varies with applied force. It converts force, pressure, tension, weight, etc. into change in the electrical resistance which can be measured. When external forces applied to a stationary object strain can be obtained. Strain is defined as displacement and deformation. The mixing chamber was checked for maximum deformation under the fluid pressure of 0.14Mpa to 0.16 Mpa and the working temperature is 200℃. Strain gauge of (LC1X) HBM type was located at moving saddle at shell junction. The following Table 6.1 shows the valve for deformation obtained analytically and experimentally.

Table No.4.1 Comparison Experimental vs. analytical results

Sr. No.	Hydro Test (Mpa)	Maximum deformation by finite element analysis (mm)	Maximum deformation by experimental (mm)
1.	0.1409	4.9241	5.0909
2.	0.1409	4.9626	5.0909
3.	0.005	4.3137	0.7781
4.	0.1598	0.2627	0.6332
5.	0.1598	0.10332	0.5243
6.	0.0041	0.10793	0.5243

As maximum deformation in the simulation and experimental process is same, in experimental process it is varied between 0.5243% - 5.0909% and in simulation process is varied between 0.10793% - 4.9241%. It can be show that finite element result is good with experimental result (± 5).

5. CONCLUSIONS AND FUTURE DIRECTIONS

Nozzle position is optimized by varying nozzle angle with finite element analysis. The optimization results show minimum stress and deformation position of nozzle. Thermal analysis shows change the support system to give space for thermal expansion Self-weight analysis of mixing chamber show that support can be used to avoid failure by deflection. Self-weight analysis and thermal analysis of mixing chamber shows that two saddles are sufficient to avoid failure by deflection. The combined analysis proves that the optimized thickness of mixing chamber is safe as per ASME sec VIII div II Part 5D, design by analysis to avoid plastic collapse. Fatigue life improvement is many times of initial fatigue life of mixing chamber. Mixing chamber can be analyzed with different pressure and temperature cycle condition w.r.t time by transient dynamic analysis. Design new mixing chamber by design by analysis Computational fluid dynamic of mixing chamber can be done to study behavior of fluid.

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