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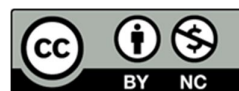


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## Simulation of Spherical Vessels for Identifying Crack-Induced Failures

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### 1. ABSTRACT

Pressure vessels play a crucial role in the oil, petrochemical, and power industries. Their maintenance, along with design and construction, is essential throughout their lifespan. This research examines a model of a cracked spherical pressure vessel using the finite element method. By modeling the fluid and considering the fluid-solid interaction, along with the wave propagation method, the position and dimensions of the crack are initially estimated. Based on the crack location and size, the stress distribution is determined. Four sensors identify the crack position, measuring 40 mm in length and 6 mm in depth, with a maximum stress of 367.5 MPa, exceeding the allowable limit. Identifying critical points around the crack, the geometric dimensions of the reinforcement should be chosen to ensure the highest safety factor. Additionally, the lifespan of these vessels can be predicted based on the damage assessment.

**Keywords:** Pressure Tanks, Spherical Tank, Crack Growth, Stress Analysis, Optimization.

### 2. INTRODUCTION

A pressure vessel according to ASME SEC VIII is defined as a container with an internal design pressure above 15 psi and below 3000 psi (1 to 206 bar). These metal vessels, typically cylindrical, spherical, or toroidal, are used to store or process liquids and gases, withstanding various loads (internal pressure, external pressure, and vacuum). The primary design standard for these vessels is ASME Section VIII, revised every four years by the American Society of Mechanical Engineers. The main criterion for compliance is having an internal pressure above 15 psi. These vessels are mainly used in the oil and gas industries.

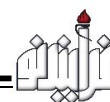
Several studies have examined different aspects of pressure vessels. Brabin et al. (2010) analyzed spherical pressure vessels with peripheral joint misalignment using finite element analysis [1]. Zhou et al. evaluated the fatigue crack initiation and growth life of pressure vessels at operating temperatures based on strain gauge measurements [2]. Li and Chen proposed toroidal pressure vessels as lighter alternatives to spherical and cylindrical geometries [3, 4]. Koussios et al. studied the optimal fiber path for composite spherical vessels with cracks using network theory [5]. Saidi et al. investigated the torsion parameters in cracked spherical pressure vessels [6], and Tutunku et al. analyzed stress in spherical vessels under mechanical loads [7]. Nebe et al. examined the impact of fatigue pressure on the vibrational and fracture behavior of spherical pressure vessels, finding that internal supports could mitigate the increased failure risk [8].

This research focuses on modeling cracked spherical vessels to identify potential hazards and develop mitigation scenarios. The study highlights the importance of finite element analysis (FEA) for stress distribution around defects and the use of J-integral and artificial neural networks for predicting three-dimensional J-integrals in surface cracks.

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Additionally, fatigue crack growth rates and stress intensity factors are crucial for evaluating operational safety. Risk-based methods, fracture assessment diagrams, and fracture mechanics parameters provide comprehensive insights into structural integrity and vessel lifespan. Simulating thermomechanical stresses and using computational fluid dynamics (CFD) models aid in understanding crack propagation and pressure rise in fire exposure scenarios. Reliability analysis based on numerical simulations emphasizes the selection of high-toughness materials and precise crack size control to enhance safety and vessel longevity.

The primary goal of this research is to model a cracked spherical vessel, identify crack locations, and analyze the lifespan and stress distribution caused by the cracks, offering solutions for maintaining vessel integrity.

### 3. MATERIALS AND METHODS

This research utilized the Eulerian Multiphase Model to simulate the phase change process following the leakage of liquefied natural gas. The Eulerian model is one of the most complex methods for simulating two-phase and multiphase flows in ANSYS Fluent. The realizable  $k-\epsilon$  model provided more accurate concentration distribution compared to the standard  $k-\epsilon$  model and was validated through simulations of heavy gas dispersion experiments. Thus, the realizable  $k-\epsilon$  model was chosen for simulating gas dispersion turbulence.

Currently, the  $k-\epsilon$  model is one of the most popular turbulence models for simulating turbulent fields in large structures like storage tanks. The standard  $k-\epsilon$  model, has significantly improved over zero and one-equation models and is widely used and validated in engineering flow calculations. However, this model may not be suitable for every component of Reynolds stress, as it assumes isotropic turbulent viscosity, whereas turbulence in curved wall flows, straight curved flows, or flows with strong swirl is anisotropic. Therefore, it is not recommended to use the standard  $k-\epsilon$  model for tanks with curved wall flows.

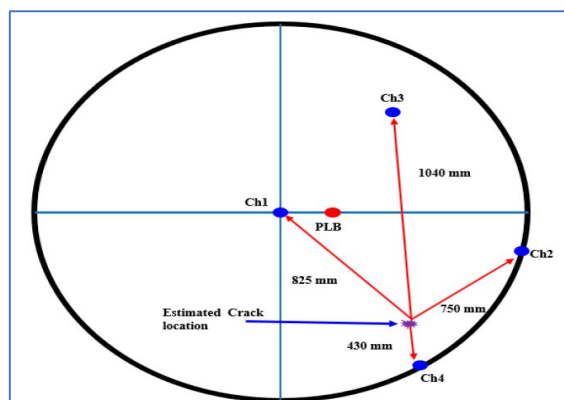
For the numerical analysis of the spherical tank structure, a precise finite element model is used, developed with ANSYS finite element software routines. The spherical shell and support columns are modeled using 3310 four-node shell elements with six degrees of freedom per node. Additionally, eight-node fluid elements with three degrees of freedom per node represent the incompressible liquid content. For a tank filled to 89%, 1793 eight-node elements are used.

Acoustic Emission (AE) testing is a common inspection method for spherical tanks. In this method, tanks are fully filled with a specified fluid to maximize stress levels. Highly sensitive AE sensors are attached to the tank wall, detecting potential cracks and fractures through acoustic signals for necessary maintenance actions.

### 4. RESULTS AND DISCUSSION

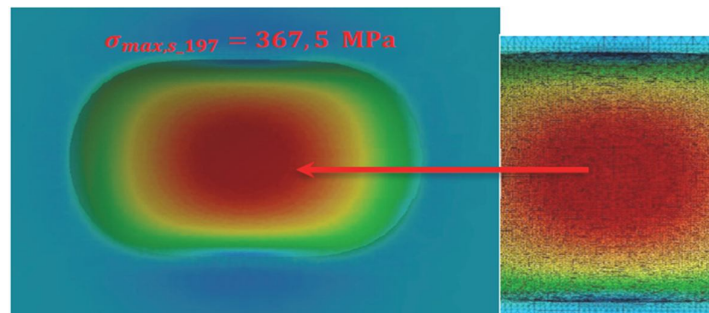
The approximate location of a crack can be determined by analyzing the waveform of acoustic signals obtained during four acoustic emission tests. Theoretically, the crack is closest to the sensor with the shortest signal arrival time. The signal arrival time at a sensor can be extracted from the signal waveform. In this study, four acoustic tests were conducted to stimulate the crack and record its signals. It is evident that in all four tests, Channel 4 received the signals first. Channel 2 received the signals slightly later than Channel 4, followed by Channel 1. Channel 3 received the signals last in all tests, indicating the longest signal arrival time. Additionally, the amplitude of signals in Channel 4 was higher compared to other channels, indicating its proximity to the crack due to less signal attenuation.

By analyzing the velocity and arrival time data, the crack location can be estimated. The estimated distances from the crack to the four channels are shown in Figure 1. It is clear that the distance between the estimated crack location and Channel 4 is the shortest. Additionally, Channel 4 received the signal well before other channels. Therefore, it can be inferred that the crack is near Channel 4.



**Figure 1.** Estimating Crack Location Using Speed and Time Technique

The maximum stress on the spherical tank shell occurs in the area below the crack with dimensions of 40 mm length, 6 mm depth, and 3 mm thickness. The stress distribution around the crack is shown in Figure 2, indicating a maximum stress of 367.5 MPa, which exceeds the allowable local stress of 360 MPa. Therefore, under such conditions, loads like seismic loads could cause compressive and tensile stresses in the tank, increasing the likelihood of crack propagation.



**Figure 2.** Stress Field Around the Crack Location

## 5. CONCLUSION

This research involved the simulation and analysis of spherical vessel to identify potential hazards from cracks. Using numerical methods and ANSYS software, a finite element model of a spherical tank was created. Fluid-solid interaction was considered, and wave propagation methods were used to locate cracks. The study determined stress distribution around the cracks, enabling a comprehensive risk assessment. Based on the findings, subsequent actions such as repairing the cracks or estimating the tank's lifespan can be decided. By accurately identifying critical points and implementing appropriate measures, the safety and reliability of these vessels can be improved, reducing risks associated with cracks.

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