

# Identification of Hazardous and Harmful Factors in Spherical Tanks

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**Abstract:** As critical pressure storage equipment in the petrochemical industry, the operational safety of spherical tanks is directly related to industrial production and public safety. This paper systematically identifies hazardous and harmful factors associated with spherical tanks and their ancillary facilities, analyzing them from multiple dimensions including structural integrity, pipelines and valves, safety systems, personnel management, and environmental conditions. The study highlights that the primary risks of spherical tanks include rupture, corrosion, explosion, and fatigue failure, which stem from design flaws, inadequate material performance, poor welding quality, abnormal external loads, and lapses in safety management. For different failure modes (e.g., strength failure, stiffness failure, and corrosion failure), preventive measures such as material optimization, structural design improvements, enhanced non-destructive testing (NDT), anti-corrosion technologies, and safety management system refinements are proposed. The research provides theoretical and technical references for the safe operation and risk management of spherical tanks, offering significant insights into enhancing the safety of pressure vessels throughout their lifecycle.

**Keywords:** Spherical tank; Hazard identification; Corrosion failure; Structural damage; Safety management; Preventive measures.

## 1. Introduction

Spherical tanks, as key pressure vessels for storing liquefied petroleum gas (LPG), liquefied natural gas (LNG), and other media, are widely used in the petrochemical industry. However, prolonged exposure to high pressure, corrosion, alternating loads, and other complex operating conditions makes them susceptible to major accidents such as leaks and explosions due to design defects, material degradation, operational errors, or environmental disasters. These incidents can result in severe casualties, economic losses, and environmental damage. Recent domestic and international case studies of spherical tank accidents demonstrate that comprehensive identification of hazardous factors and targeted mitigation measures are essential to ensuring equipment safety.

## 2. Hazardous Factors in Spherical Tanks and Ancillary Facilities

### 2.1. Spherical Tanks

#### 1. Tank Rupture

Contributing factors include:

(1) Improper foundation treatment, leading to uneven settlement or partial collapse, thereby causing wall tearing and baseplate fractures.

(2) Substandard materials or welding defects, exacerbated by inadequate inspection and extreme environmental conditions (e.g., low/high temperatures).

(3) Natural disasters such as earthquakes, landslides, or strong winds causing structural damage.

#### 2. Tank Corrosion

Leakage primarily arises from internal and external corrosion, particularly at the baseplate. Factors include degradation of internal anti-corrosion coatings, prolonged

chemical interactions with stored media, and inadequate external protection. Preventive measures include sacrificial anode protection, impressed current cathodic protection, and application of anti-rust coatings.

#### 3. Tank Explosion

Overpressure due to regulator/valve failures, unopened safety valves, and pre-existing shell defects can trigger physical explosions, leading to fires or chemical explosions.

#### 4. Tank Fatigue

Dynamic alternating loads from internal pressure and external forces induce cyclic stress, resulting in fatigue failure.

#### 5. Edge Plate Gap Leakage

Corrosive substances infiltrating gaps between the tank base and foundation can cause perforation. Waterproof seals installed at these gaps mitigate this risk.

### 2.2. Pipelines, Flanges, and Valves

#### 1. Pipeline Leakage

Pipeline leakage is a critical issue that can lead to significant safety hazards, environmental damage, and economic losses. The primary causes of pipeline leakage include: 2. Valve and Flange Failure.

**Weld Defects:** Inadequate welding procedures, improper weld joint preparation, or insufficient post-weld inspection can result in cracks, porosity, or incomplete fusion, which compromise the structural integrity of the pipeline.

**Material Corrosion:** Corrosion is a major contributor to pipeline failure, particularly in environments where the pipeline is exposed to moisture, salts, or stray electrical currents. Soil conditions, such as high chloride or sulfate content, can accelerate corrosion, leading to thinning of the pipeline walls and eventual perforation.

**Foundation Settlement:** Uneven settlement of the pipeline foundation due to soil instability or inadequate ground

preparation can cause stress concentrations, leading to pipeline distortion, cracking, or rupture.

**Third-Party Damage:** External interference, such as construction activities, excavation, or vehicle impacts, can mechanically damage pipelines, resulting in leaks or catastrophic failures.

**Natural Disasters:** Earthquakes, landslides, floods, and other natural events can exert excessive forces on pipelines, causing them to deform, fracture, or disconnect from their supports.

## 2. Valve and Flange Failure

Valves and flanges are critical components in pipeline systems, and their failure can result in uncontrolled leaks or system shutdowns. The primary causes of valve and flange failure include:

**Substandard Materials:** The use of low-quality materials in the manufacturing of valves, flanges, gaskets, or seals can lead to premature failure under operational stresses or corrosive conditions.

**Aging Gaskets and Packing:** Over time, gaskets and packing materials degrade due to thermal cycling, chemical exposure, or mechanical wear, leading to loss of sealing integrity and subsequent leakage.

**Operational Errors:** Improper handling, incorrect installation, or failure to follow maintenance procedures can result in valve or flange misalignment, over-tightening, or other issues that compromise their functionality.

## 2.3. Safety System Failures

Safety systems are designed to prevent or mitigate the consequences of equipment failures, but their malfunction can exacerbate risks. Key safety system failures include:

**Explosion-Proof Devices:** Malfunctions in explosion-proof equipment, such as flame arrestors or explosion vents, can fail to contain or redirect explosive forces, leading to uncontrolled releases of energy and potential secondary explosions.

**Pressure Relief Systems:** Inadequate design, improper installation, or failure to maintain pressure relief valves and rupture disks can result in overpressure scenarios, where the system cannot safely vent excess pressure, leading to equipment rupture or explosion.

**Isolation Barriers:** Failures in isolation valves or emergency shutdown systems can prevent the timely containment of leaks, allowing hazardous materials to spread uncontrollably.

**Safety Attachments:** Malfunctions in critical safety attachments, such as pressure gauges, temperature sensors, or level indicators, can lead to inaccurate monitoring and delayed responses to abnormal conditions.

**Firewalls and Fire Protection Systems:** Inadequate firewalls or malfunctioning fire suppression systems can fail to contain fires, allowing them to spread to adjacent equipment or storage areas, resulting in large-scale fires or explosions.

## 3. Personnel and Safety Management Risks

### 3.1. Human Factors

Human factors play a critical role in the safety and reliability of spherical tank operations. Unsafe behaviors,

such as procedural violations or deviations from established protocols, are often the root cause of accidents and incidents. These behaviors can be attributed to a combination of subjective and objective factors:

#### 1. Subjective Factors:

**Inadequate Training:** Insufficient or outdated training programs may leave personnel ill-equipped to handle complex or emergency situations, leading to errors or improper decision-making.

**Fatigue and Stress:** Prolonged working hours, high-stress environments, or inadequate rest can impair cognitive function, reduce situational awareness, and increase the likelihood of mistakes.

**Skill and Knowledge Gaps:** Variations in individual competency levels or lack of familiarity with specific equipment or procedures can result in unsafe practices.

**Attitude and Perception:** A lack of safety consciousness or an underestimation of risks can lead to complacency or deliberate non-compliance with safety protocols.

#### 2. Objective Factors:

**Personal Stressors:** External pressures, such as financial concerns, family issues, or workplace conflicts, can distract personnel and negatively impact their focus and performance.

**Workplace Environment:** Poorly designed workspaces, inadequate lighting, or excessive noise can contribute to human error by creating physical or mental discomfort.

**Organizational Culture:** A workplace culture that prioritizes productivity over safety, or one that discourages reporting of near-misses or incidents, can foster an environment where unsafe behaviors go unchecked.

Addressing human factors requires a holistic approach, including comprehensive training programs, fatigue management strategies, and fostering a safety-first culture that empowers employees to prioritize safety in all aspects of their work.

## 3.2. Safety Management Deficiencies

Effective safety management is essential for mitigating risks and ensuring the safe operation of spherical tank facilities. However, deficiencies in safety management systems can undermine these efforts and increase the likelihood of accidents. Key weaknesses include:

**Superficial Policy Implementation:** While safety policies and procedures may be well-documented, their implementation is often inconsistent or superficial. This can result from a lack of accountability, insufficient resources, or inadequate monitoring and enforcement mechanisms.

**Fragmented Risk Management:** Risk management efforts are sometimes siloed, with limited communication or coordination between departments. This fragmentation can lead to gaps in hazard identification, risk assessment, and mitigation strategies.

**Insufficient Integration of Cultural and Regulatory Approaches:** Safety management systems often focus heavily on regulatory compliance, neglecting the importance of organizational culture in driving safe behaviors. A purely compliance-driven approach may fail to address underlying cultural issues, such as resistance to change or a lack of employee engagement in safety initiatives.

**Inadequate Incident Investigation and Learning:** When incidents occur, investigations may be superficial or focused

solely on assigning blame rather than identifying root causes and implementing corrective actions. This limits the organization's ability to learn from past mistakes and prevent future occurrences.

**Lack of Continuous Improvement:** Safety management systems that do not incorporate regular reviews, audits, and updates may become outdated or ineffective over time, failing to address emerging risks or evolving industry standards.

To address these deficiencies, organizations must adopt a proactive and integrated approach to safety management. This includes fostering a culture of safety, promoting cross-functional collaboration, investing in continuous training and development, and leveraging data-driven insights to identify and mitigate risks. By addressing both human factors and systemic weaknesses, organizations can enhance their safety performance and reduce the likelihood of incidents.

## 4. Environmental Risk Factors

### 1. Natural Hazards

Natural hazards represent significant environmental risks to spherical tank facilities, as they can compromise structural integrity, disrupt operations, and lead to catastrophic failures. Key natural hazards include:

**Typhoons and Hurricanes:** These extreme weather events bring high winds, heavy rainfall, and storm surges, which can damage external structures, dislodge equipment, or flood facilities. The resulting water ingress can corrode materials, impair electrical systems, and destabilize foundations.

**Floods:** Prolonged or sudden flooding can submerge critical infrastructure, leading to equipment malfunction, chemical leakage, or structural weakening. Floodwaters may also carry debris that can physically damage tanks, pipelines, or support systems.

**Earthquakes:** Seismic activity can induce ground shaking, liquefaction, or landslides, causing tanks to shift, pipelines to rupture, or foundations to settle unevenly. The dynamic forces exerted during an earthquake can exceed design limits, leading to catastrophic structural failure.

**Extreme Temperatures:** Both high and low temperatures can adversely affect materials and equipment. Excessive heat can cause thermal expansion, degrade seals, or weaken structural components, while extreme cold can embrittle materials, freeze liquids in pipelines, or render safety systems inoperative.

**Humidity and Moisture:** High humidity levels, particularly in coastal or tropical regions, accelerate corrosion by promoting the formation of conductive electrolyte layers on metal surfaces. This can lead to thinning of tank walls, weakening of welds, and eventual failure.

**Lightning Strikes:** Lightning poses a dual threat of direct structural damage and ignition of flammable materials. A direct strike can puncture tanks or damage electrical systems, while secondary effects, such as induced currents, can disrupt instrumentation or safety controls.

Geological instability and poor site selection further exacerbate these risks. Facilities located in areas prone to landslides, sinkholes, or seismic activity are particularly vulnerable. Proper site assessment, including geological surveys and hazard mapping, is essential to mitigate these risks during the design and construction phases.

### 2. Societal Hazards

Societal hazards, often arising from human activities, pose additional risks to spherical tank facilities. These hazards can be intentional or unintentional and include:

**Third-Party Damage:** Construction activities, excavation, or transportation near facility boundaries can inadvertently damage pipelines, tanks, or support structures. Heavy machinery or equipment operating in close proximity may cause physical impacts, vibrations, or ground disturbances that compromise facility integrity.

**Vandalism and Sabotage:** Deliberate acts of vandalism or sabotage, such as tampering with safety systems, cutting pipelines, or introducing contaminants, can disrupt operations, cause leaks, or trigger explosions. These acts may be motivated by theft, protest, or malicious intent.

**Unauthorized Access:** Intrusions by unauthorized individuals, whether for theft, curiosity, or other purposes, can result in accidental damage or intentional harm. Poor perimeter security or inadequate surveillance increases the likelihood of such incidents.

**Urban Encroachment:** As urban areas expand, facilities originally located in remote or industrial zones may find themselves surrounded by residential or commercial developments. This increases the risk of accidents affecting nearby populations and complicates emergency response efforts.

Mitigating societal hazards requires a combination of physical security measures, community engagement, and regulatory oversight. Strategies include:

**Enhanced Security Systems:** Installing surveillance cameras, motion detectors, and access control systems to deter unauthorized entry and monitor facility perimeters.

**Public Awareness Campaigns:** Educating nearby communities and construction companies about the risks associated with facility operations and the importance of avoiding interference.

**Buffer Zones:** Establishing clear boundaries and buffer zones around facilities to minimize the risk of third-party damage and provide space for emergency response activities.

**Collaboration with Authorities:** Working closely with local law enforcement and emergency services to address potential threats and ensure rapid response to incidents.

## 5. Common Failure Modes

### 5.1. Strength Failure

Strength failure in spherical tanks typically manifests as ductile or brittle fractures, which can lead to catastrophic structural collapse and the release of hazardous materials. Ductile fractures occur when the material undergoes significant plastic deformation before breaking, often due to overloading or excessive stress. Brittle fractures, on the other hand, occur suddenly with little to no warning, typically in materials that have lost their toughness due to factors such as low temperatures or pre-existing flaws.

**Prevention Strategies:**

**Material Selection:** The use of high-quality materials, such as Q345R steel, which exhibits excellent mechanical properties and toughness, is critical. This steel is specifically designed for pressure vessel applications and offers superior resistance to fracture under high-stress conditions.

**Stress Concentration Reduction:** Design modifications, such as smooth transitions at geometric discontinuities (e.g., nozzle junctions), can minimize stress concentrations that often serve as initiation points for cracks.

**Non-Destructive Testing (NDT) Enforcement:** Regular and rigorous NDT inspections, including ultrasonic testing (UT), radiographic testing (RT), and magnetic particle testing (MT), are essential for detecting subsurface flaws, weld defects, or material degradation before they lead to failure.

**Residual Stress Relief:** Post-weld heat treatment (PWHT) is employed to relieve residual stresses in welded joints, reducing the risk of stress corrosion cracking (SCC) and improving the overall integrity of the structure.

**Safety Device Maintenance:** Ensuring the proper functioning of safety devices, such as pressure relief valves, rupture disks, and emergency shutdown systems, is crucial for preventing overpressure scenarios that could lead to strength failure.

## 5.2. Stiffness Failure

Stiffness failure occurs when a spherical tank or its components undergo excessive deformation or instability under pressure, compromising their ability to maintain structural integrity. This type of failure is often associated with buckling, where the tank walls or supports collapse due to compressive stresses exceeding their critical limits.

**Mitigation Measures:**

**Critical Pressure Control:** Designing the tank to operate well below its critical buckling pressure ensures that it remains stable under normal and transient conditions. This involves detailed finite element analysis (FEA) to predict and mitigate potential instability.

**Precision Manufacturing:** Strict adherence to manufacturing tolerances and quality control measures during fabrication minimizes geometric imperfections that could exacerbate deformation or instability.

**Fire-Resistant Pillar Design:** In the event of a fire, the tank's support pillars must remain stable to prevent catastrophic collapse. Using fire-resistant materials and coatings, such as intumescent paints or refractory linings, ensures that the pillars maintain their structural integrity during a fire.

## 5.3. Corrosion Failure

Corrosion failure is a pervasive issue in spherical tanks, particularly those storing corrosive media such as liquefied natural gas (LNG) or chemicals. It can manifest as uniform corrosion, where material loss occurs evenly across the surface, or as localized forms such as pitting, crevice corrosion, or stress corrosion cracking (SCC). SCC is particularly insidious, as it occurs under tensile stress in the presence of a corrosive environment, leading to sudden and catastrophic failure.

**Countermeasures:**

**Corrosion Allowance Design:** Incorporating additional material thickness (corrosion allowance) during the design phase accounts for expected material loss over the tank's service life, ensuring that the structure remains safe and functional.

**H<sub>2</sub>S Concentration Control:** In environments where hydrogen sulfide (H<sub>2</sub>S) is present, controlling its

concentration in the stored media is critical. H<sub>2</sub>S can cause sulfide stress cracking (SSC), a form of SCC that affects high-strength steels.

**Ultrasonic Testing (UT):** Regular UT inspections are essential for monitoring wall thickness and detecting localized corrosion or cracking. Advanced UT techniques, such as phased array ultrasonic testing (PAUT), provide high-resolution imaging of internal defects.

**Stress Relief Treatments:** Techniques such as PWHT or shot peening are used to reduce residual stresses in critical areas, thereby mitigating the risk of SCC.

**Protective Coatings and Linings:** Applying corrosion-resistant coatings, such as epoxy or polyurethane, and using linings made from materials like stainless steel or fiber-reinforced polymers (FRP) provide an additional barrier against corrosive media.

**Cathodic Protection:** Sacrificial anode or impressed current cathodic protection systems are employed to prevent electrochemical corrosion, particularly in submerged or buried components.

## 6. Summary

This study employs system safety engineering principles to analyze hazards in spherical tanks across structural, operational, managerial, and environmental domains. By summarizing failure modes (e.g., strength, corrosion) and their root causes, comprehensive prevention strategies—spanning design optimization, process refinement, advanced NDT, and management system enhancements—are proposed. The findings aim to standardize lifecycle safety management for spherical tanks and promote the development of safety technologies in the petrochemical industry.

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