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Assessment and Mitigation Guidelines for Lightning Risk in Old Functional Hydrocarbon Storage Tanks

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Abstract **- This research paper establishes comprehensive guidelines for conducting Lightning Risk Assessments on aging oil and gas storage tanks located within strategic terminals and refinery complexes worldwide. The focus is on tanks that have been in continuous operation for more than two to three decades since their original construction and commissioning. Given the deterioration of protective systems and evolving industry safety standards, these legacy assets present heightened vulnerability to lightning induced hazards. The study outlines a structured methodology for evaluating risk factors, including tank design limitations, grounding system degradation, insulation breakdown, and environmental exposure. It further emphasizes the integration of modern diagnostic tools, probabilistic risk modeling, and compliance with international standards (IEC, API, NFPA) to ensure reliable assessment outcomes. By providing a systematic framework, the paper aims to support asset managers, engineers, and safety regulators in mitigating lightning related risks, thereby enhancing operational reliability and safeguarding critical energy infrastructure.**

Keywords - Lightning, Storage Tanks, Refinery, Risk assessment, aging, Fire, Old Tanks, Existing Tanks, Hydro Carbon, Oil & Gas.

I. INTRODUCTION

Oil and gas storage tanks that have been in continuous operation for more than two to three decades present unique challenges when subjected to lightning risk assessments. Unlike newly constructed facilities, these legacy tanks were designed and commissioned under the standards and technologies available at the time of their construction. Consequently, their lightning protection systems often exhibit gaps when compared against the requirements of modern international standards such as IEC 62305, API RP 545, API 2003 and NFPA 780.

The primary purpose of conducting lightning risk assessments on such aging infrastructure is not merely to evaluate compliance with current standards or to propose generic solutions such as air termination poles or conventional air terminals. Instead, the objective is to derive practical, implementable recommendations that can be applied to existing tanks with minimal or no disruption and without compromising the safety and imposing major operational hurdles. This requires a deep investigation into the original tank construction practices, the lightning protection measures that were in place at the time, and the technological advancements now available in the market.

A critical aspect of this assessment is identifying the gaps between legacy designs and modern standards, and determining how these can be effectively bridged through solutions that ensure safety while maintaining operational continuity. The emphasis is on functional implementation with minimum or no downtime, recognizing that these tanks often form part of strategic energy infrastructure where prolonged outages are unacceptable as it may create the revenue loss for the Plant.

This paper provides a structured guideline for lightning risk assessment engineers, enabling them to:

- Understand the construction characteristics of older tanks and the limitations of their original protection systems.
- Compare legacy practices with current international standards and technologies.
- Develop practical retrofit strategies that enhance lightning protection without compromising ongoing operations.
- Ensure that recommendations are cost-effective, technically sound, and operationally feasible.

By bridging the gap between historical design practices and modern safety requirements, this research aims to strengthen the resilience of aging oil and gas storage facilities against lightning hazards, thereby safeguarding both personnel and critical energy assets.

II. STORAGE TANKS

This paper specifically addresses the lightning risk assessment of two critical categories of oil and gas storage tanks: External Floating Roof (EFR) Tanks and Aluminum Dome Roof (ADR) Tanks. These tank types present unique challenges in lightning protection due to their structural configurations, roof geometries, and susceptibility to ignition risks associated with volatile hydrocarbon vapours.

Other tank categories, such as fixed-roof steel tanks, Spherical Tanks, Bullet Tanks with roof or shell thicknesses exceeding 5 mm steel material, are not covered under this study. For such tank's lightning protection is comparatively straightforward. Their robust steel construction inherently provides a natural air termination system through the tank roof, while the shell plates function effectively as natural down conductors, in accordance with IEC 62305. As a result, the risk mitigation strategies for these tanks are well established and do not require the same level of detailed investigation as EFR and ADR tanks.

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In contrast, EFR Tanks and ADR Tanks demand a more rigorous assessment methodology:

External Floating Roof (EFR) Tanks

- Characterized by a floating deck that rises and falls with the liquid level.
- Vulnerable to lightning-induced sparking at seal gaps, rim seals, and metallic discontinuities.
- Require specialized evaluation of bonding, seal integrity, and equipotential continuity to prevent ignition.

Aluminum Dome Roof (ADR) Tanks

- Feature lightweight aluminum structures that differ significantly from conventional steel roofs.
- Aluminum's lower thickness and conductivity compared to steel necessitate careful analysis of air termination and down conductor pathways.
- Potential galvanic corrosion issues between aluminum and steel components further complicate lightning protection design.

By focusing on these two tank types, this paper highlights the complexity of lightning risk assessment in non-standard tank designs, where conventional assumptions about natural air terminations and down conductors are insufficient. The study emphasizes the need for deep investigations into construction practices, material properties, and the gaps between legacy protection systems and modern standards.

III.SITE SURVEY

Before initiating a lightning risk assessment, the engineer shall conduct a comprehensive site survey of the existing tanks. The objective of this survey is to collect detailed technical data that will inform the assessment process and enable the development of practical, implementable recommendations. The following aspects must be systematically verified:

Existing Lightning Protection System:

Review the philosophy and configuration currently adopted to safeguard the tanks against lightning strikes, including air terminations, down conductors, and earthing arrangements.

Tank Construction Details:

Document roof material, thickness, shell plate material, thickness, and present condition to evaluate corrosion, degradation, and structural integrity.

Aluminum Dome Roof (ADR) Tanks

Figure-1

- Inspect roof panels for punctures caused by bird attacks, hailstorms, or other mechanical damage.
- Verify the gap between ADR panels and shell plates, including the condition of bird cages or meshes installed.
- Assess feasibility of installing air terminals and down conductors on ADR structures in consultation with the OEM.
- Confirm potential for reliable earthing cable connections between ADR panels and tank shell plates.

External Floating Roof (EFR) Tanks

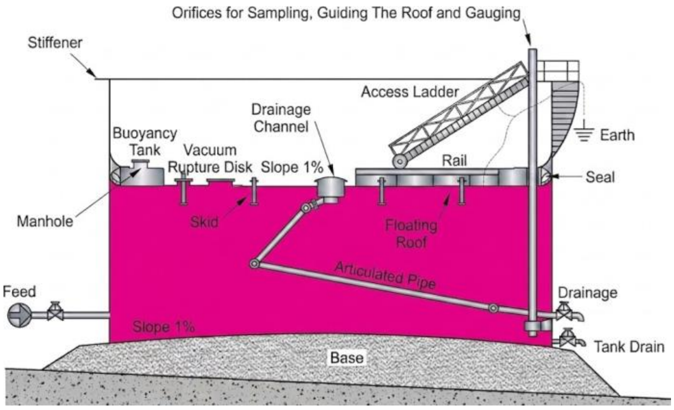

Figure-2

- Record roof material, thickness, and shell plate condition to assess corrosion and degradation.
- Inspect shunt conductors around the shell plate for integrity, continuity, and contact reliability.

Figure-3

- Verify floating roof stability, as instability can compromise shunt conductor contact with the shell plate.
- Check all earth connections between the floating roof and tank shell plate.
- Inspect earthing cable connections along rolling staircases for continuity and mechanical integrity.

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- Measure LEL (Lower Explosive Limit) levels around roof seals and verify seal condition to mitigate ignition risks.

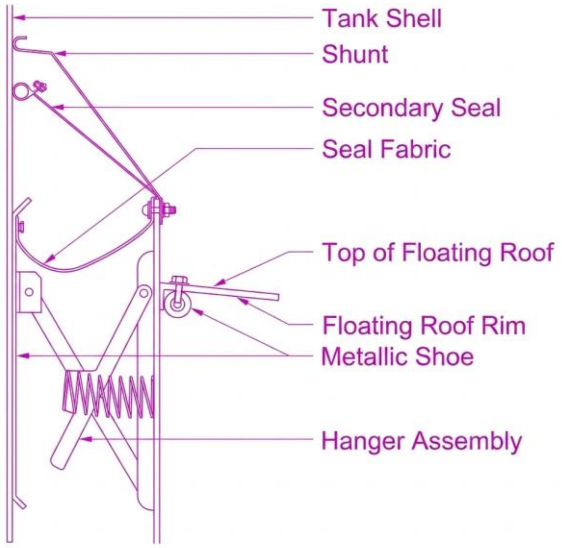

Figure-4

Roof-Top Equipment:

- Inspect lightning poles, fixtures, instrumentation, wind socks, and other rooftop installations, ensuring proper earthing and bonding.

Earthing System:

- Measure earthing resistance of pits around tanks.
- Verify connections to the main earth grid for compliance.
- Confirm isolation between the tank's cathodic protection system and lightning protection system, including insulation kits for piping flanges and spark gaps.

Site-Specific Conditions:

- Review additional earthing and lightning-related conditions in collaboration with plant operations and maintenance teams, especially for items not directly verifiable during the survey.

IV.GAP ANALYSIS

The analyzing engineer shall conduct a systematic gap analysis based on site survey observations and benchmark against prevailing international standards such as IEC 62305 **(**Lightning Protection), NFPA 780 (Standard for Lightning Protection Systems), API 545 (Lightning Protection for Aboveground Storage Tanks), API 650 (Welded Tanks for Oil Storage), API 651 (Cathodic Protection of Aboveground Petroleum Storage Tanks), and API 2003 (Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents). Practical mitigation measures shall be derived from this analysis to ensure compliance, safety, and operational reliability.

Typical Gaps Observed in Tanks Older than 20–30 Years

<u>Insufficient Earthing Connections at Tank Shell Plate:</u>

- Existing tanks typically have only 2–3 earthing points on the shell plate.
- For large-diameter tanks, a minimum of 4 earthing connections is required as per API RP 2003 Phase 1–45.
- This deficiency compromises the dissipation of lightning currents and fault currents.

<u>Corroded Earth Rods and Pits:</u>

- Earth rods and pits, often of the same age as the tanks, are severely corroded.
- Resulting high resistance values exceed acceptable limits.
- BS 6651:1999 recommends a resistance to earth of <10 ohms, which is rarely achieved in these aged installations.

<u>Degraded Earthing Connections at Tank Shell Plates:</u>

- Corrosion at connection points reduces conductivity and mechanical integrity.
- This condition is not in line with API 650 requirements, leading to ineffective bonding and compromised lightning protection.

<u>Absence of Earthing and Bonding for Ancillary Equipment:</u>

- Pipes, cables, and connected accessories are often not bonded to the tank earthing system.
- This creates potential differences and increases the risk of sparks or static discharge.

<u>Interaction with Cathodic Protection Systems:</u>

- Earthing arrangements may interfere with cathodic protection (CP), reducing CP efficiency.
- Improper design can accelerate tank bottom corrosion, undermining structural integrity.

<u>Corroded Shunts in External Floating Roof (EFR) Tanks:</u>

- Shunts, designed to maintain electrical continuity between the roof and shell, are often corroded or damaged, compromising static discharge pathways.

<u>Shunt Conductors Not Properly Contacting Tank Shell Plate:</u>

- In many cases, shunt conductors fail to maintain direct contact with the shell plate.
- This results in open circuits and ineffective bonding.

<u>Improper Spacing of Shunt Conductors:</u>

- The distance between shunt conductors is not in line with the latest API RP 2003 recommendations.

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- This reduces the effectiveness of lightning current dissipation.

Damaged Earth Cable Along EFR Rolling Staircase:

- Earth cables along rolling staircases are frequently cut or broken due to mechanical wear and movement.
- This leaves the staircase floating electrically, posing hazards during lightning strikes or static buildup.

Floating Roof Not Bonded to Tank Shell Plate:

- In many tanks, the floating roof is not bonded by direct electrical connection to the shell plate.
- NFPA 780 requires bypass conductors to ensure electrical continuity between the floating roof and tank shell.
- Absence of this bonding increases the risk of ignition from lightning or static discharge.

Inadequate Floating Roof Thickness in EFR Tanks:

- Floating roof thickness is often <5 mm steel, which is not compliant with IEC 62305-3.
- Such thin material cannot act as a reliable natural dissipating path for lightning strokes without proper shunting and bypass conductors.
- This increases vulnerability to direct lightning damage.

Insufficient Aluminium Roof Thickness in ADR Tanks:

- Aluminium roofs are often less than 2 mm thick, which is below the IEC 62305 requirement for natural lightning dissipation.
- Without adequate thickness or supplementary measures (air terminations, down conductors), these roofs cannot safely dissipate lightning energy.
- This creates a high ignition risk in volatile storage environments.

V. SCENARIOS FOR ASSESSMENT

During the assessment and mitigation planning phase, the engineer shall ensure that all critical flashover scenarios are systematically addressed. The proposed recommendations must provide comprehensive support across the following three conditions:

Current routes for flash to the top of the tank shell

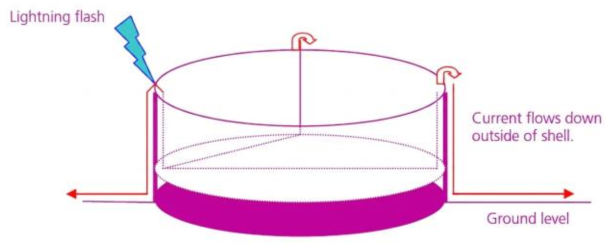

Figure-5

Current routes for flash to the tank roof

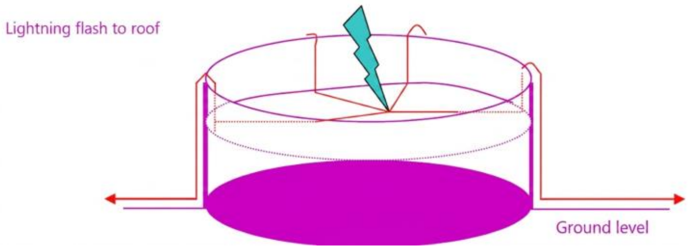

Figure-6

Current routes for flash to the ground adjacent to the tank roof structure

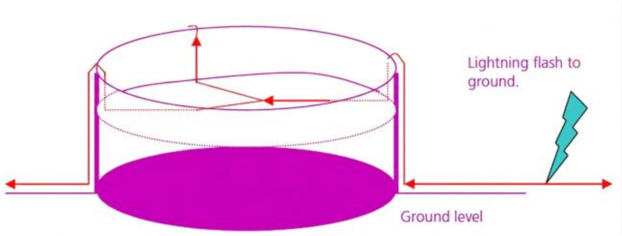

Figure-7

VI. ESTABLISHED TANK PRACTICES

In older External Floating Roof (EFR) hydrocarbon tanks, three principal lightning protection practices are generally adopted to mitigate flashover risks and ensure compliance with international standards.

Enhance Shunt Conductor Integrity

- Improve material quality and optimize spacing to ensure reliable electrical continuity between floating roof and shell.
- Replace degraded shunt conductors with corrosion-resistant materials (e.g., tinned copper)
- Maintain uniform spacing around the tank circumference to minimize potential differences
- Verify mechanical stability and contact pressure during roof movement.

Figure-8

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Implement Bypass Conductors

- Install retractable earthing lines in accordance with NFPA guidelines to provide a low-impedance path for lightning current.
- Deploy retractable bypass conductors between floating roof and shell
- Ensure compliance with NFPA 780 spacing and installation requirements
- Periodically inspect for mechanical wear and contact reliability.

Figure-9

Apply MAG or Equivalent Systems

- Integrate a Mechanical Active Grounding (MAG) or equivalent system to provide continuous bonding during roof movement.
- Install MAG systems or equivalent engineered solutions
- Ensure dynamic contact between floating roof and shell during all operating positions
- Validate performance through resistance measurement and simulation studies

Figure-10

VII. PRACTICES NOT RECOMMENDED

In certain legacy large-diameter hydrocarbon storage tanks, engineers have attempted to treat the tank as a building structure and apply the rolling sphere method for lightning protection. This approach typically involves installing tall independent towers or poles along the perimeter of the tank to achieve theoretical coverage. Where complete rolling sphere coverage is still not achievable, some facilities have resorted to tying ropes or conductors diagonally across the towers to simulate a Faraday cage effect.

However, this methodology is not recommended for aging tanks due to significant practical and maintenance-related constraints:

Tank Bottom Replacement:

Old tanks often require bottom plate replacement due to corrosion. This process involves lifting the entire tank using hydraulic jacks. The presence of perimeter towers, diagonal ropes, or cage structures creates severe obstructions to lifting operations and restricts access for heavy equipment.

HDP Liner and soil Replacement:

Replacement or repair of High-Density Polyethylene (HDP) liners beneath the tank bottom demands unobstructed clearance. Faraday cage installations interfere with liner removal and reinstallation.

Cathodic Protection Systems:

Maintenance or installation of new cathodic protection systems for the tank bottom and annular plate requires free access around the tank perimeter. Rope-based cage structures hinder the routing of cables, installation of anode beds, and inspection of isolation kits or spark gaps.

Operational Safety:

Temporary cage structures introduce additional mechanical hazards during maintenance, increasing the risk of entanglement, collapse, or interference with scaffolding and lifting systems.

Thus, while the rolling sphere and Faraday cage concepts may appear theoretically viable for large-diameter tanks, their practical application is incompatible with essential maintenance requirements. Modern lightning protection strategies for EFR tanks should instead prioritize direct bonding improvements, bypass conductors, and advanced arc-gap technologies, which provide effective protection without obstructing future maintenance activities.

VIII. CONCLUSION

Lightning strikes remain the predominant cause of hydrocarbon storage tank fires and explosions, accounting for nearly half of all incidents in atmospheric tanks worldwide. Statistical evidence consistently shows that 30–50% of tank farm fires originate from lightning events, underscoring the critical vulnerability of these assets.
For tanks that have been in continuous service for 20–30 years or more, the risk is further amplified due to material degradation, corrosion, and structural wear. Aging infrastructure often lacks modern protective measures, making

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it imperative to conduct comprehensive lightning risk assessments.

A robust mitigation plan must therefore:

- Identify and evaluate flashover routes to the shell, roof, and ground.
- Implement modern protective practices such as improved shunt conductors, bypass earthing lines, MAG system, and advanced arc-gap systems etc.
- Ensure compatibility with maintenance requirements, avoiding methods such as independent poles and tower around the perimeter of the tank that obstruct bottom plate replacement, HDP liner repair, or cathodic protection upgrades etc.

By integrating systematic lightning assessment with technically sound mitigation strategies, operators can significantly reduce fire and explosion scenarios, safeguard aging hydrocarbon tanks, and ensure compliance with international standards.

IX.REFERENCE

- IEC 62305 – Protection Against Lightning
- API545 – Recommended Practice for Lightning Protection of Aboveground Storage Tanks for Flammable or Combustible Liquids
- API 2003 – Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents
- NFPA 780 – Standard for the Installation of Lightning Protection Systems
- API 650 – Welded Tanks for Oil Storage
- API 651 – Cathodic Protection of Aboveground Petroleum Storage Tanks