

Inspection Practices for Atmospheric and Low-pressure Storage Tanks

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Inspection Practices for Atmospheric and Low-pressure Storage Tanks

1 Scope

This document provides useful information and recommended practices for the maintenance and inspection of atmospheric and low-pressure storage tanks. Although these maintenance and inspection guidelines may apply to other types of tanks, these practices are intended primarily for existing tanks that were designed and constructed to API aboveground storage tank standards or specifications, as referenced in 2.2.

This document addresses the following:

- a) descriptions and illustrations of the various types of storage tanks;
- b) new tank construction standards;
- c) maintenance practices;
- d) reasons for inspection;
- e) causes of deterioration;
- f) frequency of inspection;
- g) methods of inspection;
- h) inspection of repairs;
- i) preparation of records and reports;
- j) safe and efficient operation;
- k) leak prevention methods.

This recommended practice is intended to supplement API 653 (applicable for all tanks) and API 12R1 (as applicable for the API 12 series tanks storing production liquids) that provide minimum requirements for maintaining the integrity of storage tanks after they have been placed in service.

2 Normative References

2.1 Codes, Standards, and Related Publications

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Standard 653, *Tank Inspection, Repair, Alteration, and Reconstruction*

2.2 Other References

The following codes and standards are cited in the text of this recommended practice or included in the knowledge base to develop this document. Familiarity with these documents is suggested as they provide additional information pertaining to the inspection and repair of aboveground storage tanks.

API Standard 12A, *Specification for Oil Storage Tanks with Riveted Shells* (withdrawn)

API Specification 12B, *Specification for Bolted Tanks for Storage of Production Liquids*

API Standard 12C, *Specification for Welded Oil Storage Tanks* (withdrawn)

API Specification 12D, *Specification for Field-welded Tanks for Storage of Production Liquids*

API Standard 12E, *Specification for Wooden Production Tanks* (withdrawn)

API Specification 12F, *Specification for Shop-welded Tanks for Storage of Production Liquids*

API Specification 12P, *Specification for Fiberglass Reinforced Plastic Tanks*

API Standard 12R1, *Installation, Operation, Maintenance, Inspection, and Repair of Tanks in Production Service*

API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 2, *Tank Calibration*

API MPMS Chapter 19.2, *Evaporative Loss from Floating-roof Tanks*

API 510, *Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair, and Alteration*

API 570, *Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems*

API Recommended Practice 571, *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry*

API Recommended Practice 572, *Inspection Practices for Pressure Vessels*

API Recommended Practice 576, *Inspection of Pressure-relieving Devices*

API Recommended Practice 579-1/ASME FFS-1, *Fitness-For-Service*

API Recommended Practice 580, *Elements of a Risk-Based Inspection Program*

API Recommended Practice 581, *Risk-Based Inspection Methodology*

API Recommended Practice 583, *Corrosion Under Insulation and Fireproofing*

API Standard 598, *Valve Inspection and Testing*

API Standard 620, *Design and Construction of Large, Welded, Low-pressure Storage Tanks*

API Standard 625, *Tank Systems for Refrigerated Liquefied Gas Storage*

API Standard 650, *Welded Tanks for Oil Storage*, 13th Edition

API Recommended Practice 651, *Cathodic Protection of Aboveground Petroleum Storage Tanks*

API Recommended Practice 652, *Linings of Aboveground Petroleum Storage Tank Bottoms*

API Technical Report 654, *Aboveground Storage Tank Caulking or Sealing the Bottom Edge Projection to the Foundation*

API Technical Report 655, *Vapor Corrosion Inhibitors for Storage Tanks*

API Bulletin 939-E, *Identification, Repair, and Mitigation of Cracking of Steel Equipment in Fuel Ethanol Service*

API Standard 2000, *Venting Atmospheric and Low-pressure Storage Tanks*

API Recommended Practice 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*

API Standard 2015, *Requirements for Safe Entry and Cleaning of Petroleum Storage Tanks*

API Standard 2350, *Overfill Prevention for Storage Tanks in Petroleum Facilities*

API Standard 2610, *Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities*

ACI 376-11¹, *Code Requirements for Design and Construction of Concrete Structures for the Containment of Refrigerated Liquefied Gases and Commentary*

AISC ², *Steel Construction Manual*

ASME Boiler and Pressure Vessel Code (BPVC) ³, Section V: *Nondestructive Examination*

ASME BPVC, Section VIII: *Rules for the Construction of Pressure Vessels*

ASME BPVC, Section IX: *Welding, Brazing, and Fusing Qualifications*

ASME PCC-2, *Repair of Pressure Equipment and Piping*

ASNT CP-189 ⁴, *Standard for Qualification and Certification of Nondestructive Testing Personnel*

ASNT SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*

ASTM D3359 ⁵, *Standard Test Methods for Rating Adhesion by Tape Test*

EEMUA 159 ⁶, *Above ground storage flat bottom storage tanks: A guide to inspection, maintenance and repair*

NFPA 11 ⁷, *Flammable Standard for Low-, Medium-, and High-Expansion Foam*

NFPA 30, *Flammable and Combustible Liquids Code*

OSHA ⁸, 29 Code of Federal Regulations (CFR) Part 1910.23, *Ladders*

OSHA, 20 CFR Subpart D, *Walking-Working Surfaces*

OSHA, 29 CFR Part 1910.106, *Flammable Liquids*

OSHA, 29 CFR Part 1910.146, *Permit-required Confined Spaces*

¹ American Concrete Institute, 38800 Country Club Drive, Farmington Hills, Michigan 48331, www.concrete.org.

² American Institute of Steel Construction, 130 East Randolph, Suite 2000, Chicago, Illinois 60601, www.aisc.org.

³ ASME International, Two Park Avenue, New York, New York 10016, www.asme.org.

⁴ American Society for Nondestructive Testing, 1201 Dublin Road, Suite G04, Columbus, Ohio 43215, www.asnt.org.

⁵ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

⁶ Engineering Equipment and Materials Users Association, Leytonstone House, 3 Hanbury Drive, London, E11 1GA, United Kingdom, www.eemua.org.

⁷ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169, www.nfpa.org.

⁸ U.S. Department of Labor, Occupational Safety and Health Administration, 200 Constitution Avenue NW, Washington, DC 20210, www.osha.gov.

STI SP001 ⁹, *Standard for Inspection of Aboveground Storage Tanks*

UL 142 ¹⁰, *Standard for Safety Steel Aboveground Tanks for Flammable and Combustible Liquids*

US EPA AP-42 ¹¹, *Compilation of Air Emissions Factors from Stationary Sources*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1

alteration

Any work on a tank that changes its physical dimensions or configuration.

3.1.2

atmospheric pressure

When referring to vertical tanks, the term “atmospheric pressure” usually means tanks designed to API 650, although API 620 uses the term “atmospheric pressure” to describe tanks designed to withstand an internal pressure not exceeding the weight of the roof plates. API 650 also provides for rules to design tanks for “higher internal pressure” up to 2.5 psi (18 kPa). API 653 uses the generic meaning for atmospheric pressure to describe tanks designed to withstand an internal pressure up to, but not exceeding, 2.5 psi (18 kPa) gauge.

3.1.3

authorized inspection agency

Any one of the following:

- a) the inspection organization of the jurisdiction in which the aboveground storage tank is operated;
- b) the inspection organization of an insurance company that is licensed or registered to and does write aboveground storage tank insurance;
- c) an owner-operator of one or more aboveground storage tank(s) who maintains an inspection organization for activities relating only to their equipment and not for aboveground storage tanks intended for sale or resale;
- d) an independent organization or individual that is under contract to and under the direction of an owner-operator and recognized or otherwise not prohibited by the jurisdiction in which the aboveground storage tank is operated; the owner-operator’s inspection program shall provide the controls necessary for use by authorized inspectors contracted to inspect aboveground storage tanks.

3.1.4

authorized inspector

An employee of an authorized inspection agency who is qualified and certified to perform inspections under API 653; whenever the term “inspector” is used in API 575, it refers to an authorized aboveground API 653 inspector.

⁹ Steel Tank Institute/Steel Plate Fabricators Association (STI/SPFA), 944 Donata Court, Lake Zurich, Illinois 60047, www.steeltank.com.

¹⁰ Underwriters Laboratories, 333 Pfingsten Road, Northbrook, Illinois 60062, www.ul.com.

¹¹ U.S. Environmental Protection Agency, 1200 Pennsylvania Avenue NW, Washington, DC 20004, www.epa.gov.

3.1.5**condition monitoring location****CML**

Designated areas on tanks where periodic examinations are conducted to directly assess the condition of the tank. Condition monitoring locations (CMLs) may contain one or more examination points and utilize multiple inspection techniques that are based on the predicted damage mechanism to give the highest probability of detection. CMLs can be a single small area on a tank (e.g. a 2-in. diameter spot or a plane through a section of a nozzle) where recording points exist in all four quadrants of the plane.

NOTE CMLs include, but are not limited to, thickness measurement locations.

3.1.6**corrosion allowance**

Additional material thickness available to allow for metal loss during the service life of the tank component.

3.1.7**corrosion rate**

The total metal loss divided by the period of time over which the metal loss occurred.

3.1.8**corrosion specialist**

A person, acceptable to the owner-operator, who has knowledge and experience in corrosion damage mechanisms, metallurgy, materials selection, and corrosion monitoring techniques.

3.1.9**corrosion under insulation****CUI**

External corrosion of materials of tanks and structural components resulting from water trapped under insulation; external chloride stress corrosion cracking (SCC) of austenitic and duplex stainless steel under insulation is also classified as corrosion under insulation (CUI) damage.

3.1.10**damage mechanism**

Any type of deterioration encountered in the refining and chemical process industry that can result in flaws or defects that can affect the integrity of tanks (e.g. corrosion, cracking, erosion, dents, and other mechanical, physical, or chemical impacts); see API 571 for a comprehensive list and description of damage mechanisms.

3.1.11**defect**

An imperfection whose type or size exceeds the applicable acceptance criteria and is therefore rejectable.

3.1.12**documentation**

Records containing descriptions of specific tank design, personnel training, inspection plans, inspection results, nondestructive examination (NDE), repair, alteration, operating heights or capacities, fitness-for-service (FFS) assessments, procedures for undertaking these activities, or any other information pertinent to maintaining the integrity and reliability of the tank.

3.1.13**examinations**

A process by which an examiner or inspector investigates a component of the tank using NDE in accordance with approved NDE procedures (e.g. inspection of a CML, quality control of repair areas).

3.1.14**examiner**

A person who assists the inspector by performing specific NDE on aboveground storage tanks and evaluates to the applicable acceptance criteria but does not interpret the results of those examinations in accordance with API 653, unless specifically trained and authorized to do so by the owner-operator.

3.1.15**external inspection**

A formal visual inspection, conducted or supervised by an authorized inspector, to assess all aspects of the tank as possible without suspending operations or requiring tank shutdown.

3.1.16**fitness-for-service assessment****FFS assessment**

A methodology whereby flaws contained within a structure are assessed in order to determine the adequacy of the flawed structure for continued service without imminent failure.

3.1.17**general corrosion**

Corrosion that is distributed more or less uniformly over the surface of the metal, as opposed to localized corrosion.

3.1.18**heat-affected zone**

The portion of the base metal whose mechanical properties or microstructure have been altered by the heat of welding or thermal cutting.

3.1.19**hydrostatic pressure**

The pressure exerted by a fluid at equilibrium at a given point within the fluid, due to the force of gravity. Hydrostatic pressure increases in proportion to the depth measured from the surface because of the increasing weight of the fluid exerting downward force from above.

3.1.20**indications**

A response or evidence resulting from the application of NDE that may be nonrelevant, flawed, or defective upon further analysis.

3.1.21**in service**

Designates a tank that has been placed in operation as opposed to new construction prior to being placed in service or retired tanks. A tank not in operation because of a process outage is still considered an in-service tank.

NOTE Does not include tanks that are still under construction or in transport to the site prior to being placed in operation or tanks that have been decommissioned. It does include tanks that are temporarily out of service but still in place in an operating site. A stage in the service life of a tank between installation and being decommissioned.

3.1.22**inspection**

The external, internal, or in-service evaluation (or any combination of the three) of the condition of a tank conducted by the authorized inspector or their designee in accordance with API 653.

3.1.23**inspection plan**

A strategy defining how and when a tank or its devices will be inspected, repaired, and/or maintained.

3.1.24**inspector**

A shortened title for an authorized tank inspector qualified and certified in accordance with API 653.

3.1.25**internal inspection**

A formal, complete inspection, as supervised by an authorized inspector, of all accessible internal tank surfaces.

NOTE Refer to API 653 definition for this term when referenced in API 575.

3.1.26**jurisdiction**

A legally constituted governmental administration that may adopt rules relating to tanks.

3.1.27**localized corrosion**

Corrosion that is largely confined to a limited or isolated area of the metal surface of a tank.

3.1.28**magnetic flux leakage****MFL**

An electromagnetic scanning technology for tank bottoms also known as MFE (magnetic flux exclusion).

3.1.29**minimum acceptable thickness**

The lowest thickness at which a tank component should operate, as determined by the parameters in the applicable tank design standard (such as API 650, API 653, etc.), the FFS principles in API 579-1/ASME FFS-1, or other appropriate engineering analysis.

3.1.30**owner-operator**

The legal entity having control of and/or responsibility for the operation and maintenance of an existing storage tank.

3.1.31**procedures**

A document that specifies or describes how an activity is to be performed. It may include methods to be employed, equipment or materials to be used, qualifications of personnel involved, and sequence of work.

3.1.32**product-side**

The side of the tank that is in contact with the stored liquid.

3.1.33**reconstruction**

Any work necessary to reassemble a tank that has been dismantled and relocated to a new site.

3.1.34**reconstruction organization**

The organization having assigned responsibility by the owner-operator to design and/or reconstruct a tank.

3.1.35**release prevention barrier
RPB**

The second bottom of double steel bottom tanks, synthetic materials, clay liners, and all other barriers or combination of barriers placed under an aboveground storage tank, which have the following functions:

- a) preventing the escape of contaminated material;
- b) containing or channeling released material for leak detection.

NOTE See nonmandatory Annex I of API 650.

3.1.36**repair**

Work necessary to maintain or restore a tank to a condition suitable for safe operation. Repairs include both major repairs and repairs that are not major repairs. Examples of repairs include the following:

- a) removal and replacement of material (such as roof, shell, or bottom material, including weld metal) to maintain tank integrity;
- b) releveling and/or jacking of a tank shell, bottom, or roof;
- c) adding or replacing reinforcing plates (or portions thereof) to existing shell penetrations;
- d) repair of flaws, such as tears or gouges, by grinding and/or gouging followed by welding.

3.1.37**risk-based inspection
RBI**

A risk assessment and management process that is focused on loss of containment of equipment in facilities due to material deterioration. These risks are managed primarily through equipment inspection.

3.1.38**soil-side**

The side of the tank bottom that is in contact with the ground.

3.1.39**storage tank engineer**

One or more persons or organizations acceptable to the owner-operator who are knowledgeable and experienced in the engineering disciplines associated with evaluating mechanical and material characteristics that affect the integrity and reliability of aboveground storage tanks. The storage tank engineer, by consulting with appropriate specialists, should be regarded as a composite of all entities needed to properly assess the technical requirements.

3.1.40**temporary repairs**

Repairs made to storage tanks to restore sufficient integrity to continue safe operation until permanent repairs are conducted.

3.1.41**vapor corrosion inhibitor
VCI**

volatile corrosion inhibitor

Chemical substances that slowly release a corrosion-preventative compound into an enclosed airspace, effectively protecting exposed metal surfaces.

3.2 Acronyms and Abbreviations

AST	aboveground storage tank
BS&W	bottom sediment and water
CML	condition monitoring location
CUI	corrosion under insulation
FFS	fitness-for-service
MFL	magnetic flux leakage
MIC	microbial induced corrosion
NDE	nondestructive examination
RBI	risk-based inspection
RPB	release prevention barrier
SCC	stress corrosion cracking
UT	ultrasonic thickness
VCI	vapor corrosion inhibitor
WFMT	wet fluorescent magnetic particle testing

4 Types of Storage Tanks

4.1 General

4.1.1 Tank Design and Materials

Storage tanks are used to store fluids, such as crude oil, intermediate and refined products, gas, chemicals, waste products, water, and water/product mixtures. Aboveground storage tank minimum requirements for design are covered within documents referenced in 2.2. Important factors, such as the volatility of the stored fluid and the desired storage pressure and temperature, result in tanks being built of various types, sizes, and materials of construction. In this document, only atmospheric and low-pressure storage tanks are considered. Guidelines for inspection of pressure vessels operating at pressures greater than 15 psi (103 kPa) gauge are covered in API 572.

There are two types of tanks commonly found in industry: fixed roof and floating roofs. Fixed-roof tanks can be constructed out of carbon steel, alloy steel, aluminum, or other metals. In addition to these materials, tanks can be constructed out of nonmetallic materials such as concrete, reinforced thermoset plastics, and wood (API 12E). Floating-roof tanks are commonly made out of carbon steel but can also be made of other alloys, as well as composite materials. Floating roofs can be characterized as full contact floating roofs, or partial contact floating roofs, depending on the amount of their bottom side surfaces that is in direct contact with the product stored. Atmospheric tanks are generally welded but can also be riveted (API 12A) or bolted (API 12B).

4.1.2 Storage Tanks with Linings, Cathodic Protection, and/or Vapor Corrosion Inhibitors

Where internal corrosion is experienced or expected, tanks can be lined with a variety of corrosion-resistant materials, such as coatings of epoxy or vinyl ester, fiberglass, poured or sprayed concrete, alloy steel, aluminum, rubber, lead, synthetics such as high-density polyethylene or other synthetic rubber, and glass.

See API 652 for provisions for the application of some types of tank bottom linings to both existing and new storage tanks.

Cathodic protection systems are often provided for control of external bottom corrosion and, combined with internal linings, may also be used to protect tank bottoms internally. See API 651 for design, maintenance, and monitoring recommendations for such systems.

As an alternative or supplement to cathodic protection, some utilize vapor corrosion inhibitors (VCIs) to protect the underside of the tank bottom from corrosion. See API 655 for information regarding the design, use, and maintenance of VCIs for under-bottom AST corrosion protection.

4.1.3 Storage Tanks with Passive Leak Detection Systems

Leak detection systems are installed for early awareness of a potential leak. API 650—Annex I provides design guidelines for leak detection and subgrade protection. Reference also API 306, API 307, API 315, API 322, API 323, API 325, API 340, and API 341 for additional information on leak detection systems for storage tanks and dike containment areas.

4.1.4 Storage Tanks with Optional Auxiliary Equipment

Storage tanks are provided with some of the following auxiliary equipment, such as liquid-level gauges, high- and low-level alarms, and other overfill prevention systems (see API 2350), pressure-relieving devices (see API 2000), vacuum venting devices, emergency vents, gauging hatches, roof drain systems, flame arrestors, fire protection systems (see NFPA 11), and mixing devices.

Stairways, ladders, platforms, handrails, piping connections and valves, manholes, electric grounding connections (as required), and cathodic protection systems and VCI systems are considered examples of storage tank auxiliary equipment.

Insulation may also be present to maintain product temperature. Insulation can vary from externally jacketed panel systems to sprayed-on foam systems to loose-fill systems in double-wall tank construction.

Heating systems are a type of auxiliary equipment that a storage tank may have. This may include heating coils, steam tracing, electrical tracing, and a bundle installed in a large nozzle.

Agitators are a type of auxiliary equipment that a storage tank may have. This may include a single or multiple agitators installed through large nozzles similar to a bundle.

Inspection and failure of auxiliary equipment are covered in 5.4.

4.2 Atmospheric Storage Tanks

4.2.1 Construction, Materials, and Design Standards

Atmospheric storage tanks are designed to operate with internal gas and vapor spaces at pressures close to atmospheric pressure. Such tanks are usually constructed of carbon steel, alloy steel, aluminum, or other metals, depending on service. Additionally, some tanks are constructed of nonmetallic materials, such as reinforced concrete, reinforced thermoset plastics, and wood. Some wooden tanks constructed to API 12E are still in service. Atmospheric storage tanks are generally welded. Some riveted tanks constructed to API 12A and some bolted tanks constructed to API 12B can also be found still in service. Information for the construction of atmospheric storage tanks is given in API 12A (withdrawn), API 12B, API 12C (the predecessor to API 650 and now withdrawn), API 12D, API 12E (withdrawn), API 12F, API 650, API 620, and API 2000. API 625 covers the selection, design, and construction of tank systems for refrigerated liquefied gas storage on land. API 653 provides information pertaining to requirements for inspection, repair, alteration, and reconstruction of aboveground storage tanks.

4.2.2 Use of Atmospheric Storage Tanks

Atmospheric storage tanks in the petroleum industry are normally used for fluids having a true vapor pressure that is less than atmospheric pressure. Vapor pressure is the pressure on the surface of a confined liquid caused by the vapors of that liquid. Vapor pressure increases with increasing temperature. Crude oil, heavy oils, gas oils, furnace oils, naphtha, gasoline, and nonvolatile chemicals are usually stored in atmospheric storage tanks. Many of these tanks are protected by pressure/vacuum vents that limit the pressure difference between the tank vapor space and the outside atmosphere to a few ounces per square inch.

Non-petroleum industry uses of atmospheric tanks include storage of a variety of chemicals and other substances operated in closed-loop systems not vented to atmosphere and with pressure control and relief devices as required. These tanks may be designed and operated as low-pressure storage tanks per API 620. See 4.3 for additional information on tanks operated at low pressure.

Additional uses for atmospheric storage tanks can include the storage of liquid (both hydrocarbon and non-hydrocarbon) in horizontal tanks, and process liquids or granular solids in skirt-supported or column-supported tanks with elevated cone bottoms (non-flat bottom), and the storage of process water/liquids in open-top tanks.

4.2.3 Types of Atmospheric Storage Tank Roofs

4.2.3.1 Fixed Cone Roof Tanks

The most common type of atmospheric storage tank is the fixed cone roof tank (see Figure 1). Fixed cone roof tanks may typically be up to 300 ft (91.5 m) in diameter and 64 ft (19.5 m) in height, although larger-diameter tanks have been built. These roofs are normally supported by internal structural rafters, girders, and columns but can be fully self-supporting in smaller diameters [typically 60 ft (18.3 m) diameter or less]. Self-supporting aluminum dome roofs (e.g. geodesic dome roofs) may be applied to most diameter tanks without the need for internal supporting columns.

A steel cone roof may include a “frangible joint” (weak roof-to-shell joint) which is of benefit to allow emergency release of internal pressure, while avoiding shell uplift and potential failure of the bottom-to-shell joint. The mechanism allowing roof-to-shell joint failure is the shell and top angle joint buckling under compression as the roof rotates during uplift, leading to the tearing of the peripheral weak seam weld.



Figure 1—Fixed Cone Roof Tank

4.2.3.2 Domed Roof Tanks

The self-supporting aluminum dome roof tank (see Figure 2) and the umbrella roof tank (see Figure 3) are variations of the fixed-roof tank. The steel dome roofs are clear span self-supporting from the top of the tank shell without columns and are often used with pressurized tanks.



Figure 2—Self-supporting Dome Roof Tank

4.2.3.3 Umbrella Roof

The umbrella roof has radially arched segmental plates with integral framing support members (usually without internal support columns).



Figure 3—Umbrella Roof Tank

4.2.3.4 Geodesic Dome Roof

The geodesic dome is of aluminum construction and is self-supported (see Figure 4). The addition of the geodesic dome can reduce product vapor loss or eliminate the need to drain rainwater from the roof. The geodesic dome can be installed at new construction or retroactively over existing external floating-roof tanks. Minimum requirements for the geodesic dome roof are defined in API 650—Annex G for use as a fixed roof (with or without a floating roof). The construction is clear span and self-supported from the rim of the tank. An alternative design in API 650—Annex G permits transfer of the radial forces to an “external tension ring” (typically steel) with fixed dome supports, where the top of the shell/wind-girder is additionally reinforced to retain the radial tension/compression forces from the dome in combination with wind acting on the shell as an open-top tank. The latter design results in reduced aluminum dome material (eliminating the aluminum integral tension ring), offsetting the additional steel and increased tank design requirements. The external tension ring option usually becomes efficient for new tanks at diameter of 200’ or greater and is typically the only option for tanks exceeding 300’ in diameter, except for true “geodesic” designs that have minimal radial force transfer.



Figure 4—Self-supporting Aluminum (Geodesic) Dome Roof Tank

4.2.4 Types of Floating Roofs for Atmospheric Storage

4.2.4.1 Open-top External Floating-roof Tanks

4.2.4.1.1 General

Tanks without a fixed roof are referred to as open-top or external floating-roof tanks. The external floating-roof tank is designed to minimize filling and breathing losses by eliminating or minimizing the vapor space above the stored liquid. The shell and bottom of this type of tank are similar to those of the fixed-roof tanks, but in this case, the roof is designed to float on the surface of the stored liquid. In instances where the shell is not braced to resist buckling from the wind, a wind-girder will be included as part of the shell design.

4.2.4.1.2 Steel Pan Floating Roof

The steel pan floating roof is a single steel deck designs without annular pontoons as shown in Figure 5. This external floating roof type is no longer permitted under API 650—Annex C. Such roofs have no reserve buoyancy and are susceptible to sinking in service.

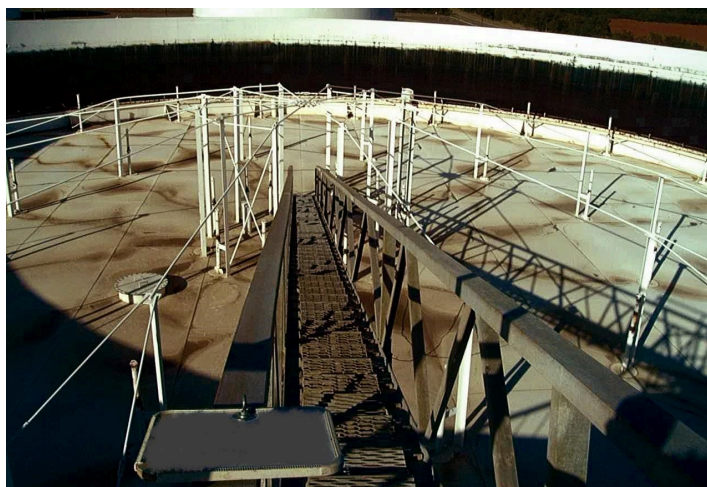


Figure 5—Externally Stiffened Pan-type Floating-roof Tank

Caution—The externally stiffened pan-type floating roof is no longer allowed to be constructed per API 650—Annex C, although many still remain in use.

4.2.4.1.3 Variations

Annular-pontoon and double-deck roofs are shown in Figure 6 and Figure 7, respectively.

External floating roofs are designed in accordance with API 650—Annex C. A “domed external floating roof” is a type designed as an external floating roof, except it is covered with a clear span aluminum dome roof and vented in accordance with API 650—Annex H. These domed external floating-roof tanks are considered internal floating roofs for tank venting and confined space entry purposes; however, the floating roof is the emission control device and the fixed aluminum dome modifies emission factors applied to liquid surface temperature, seals, and deck fittings.

Refer to API MPMS Ch. 19.2 *Evaporative Loss from Floating-roof Tanks* for further means to evaluate evaporation/emission loss for various types of floating-roof tanks and their respective fittings.

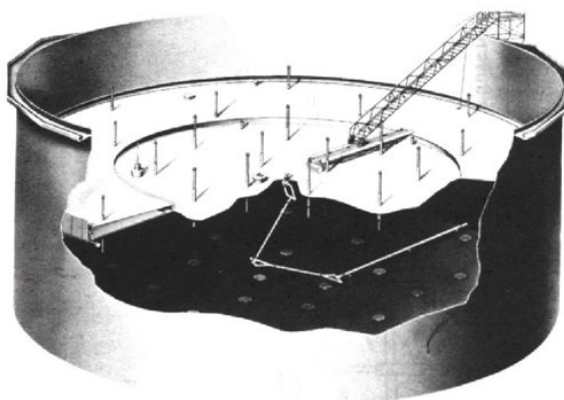


Figure 6—Annular-pontoon Floating-roof Tank

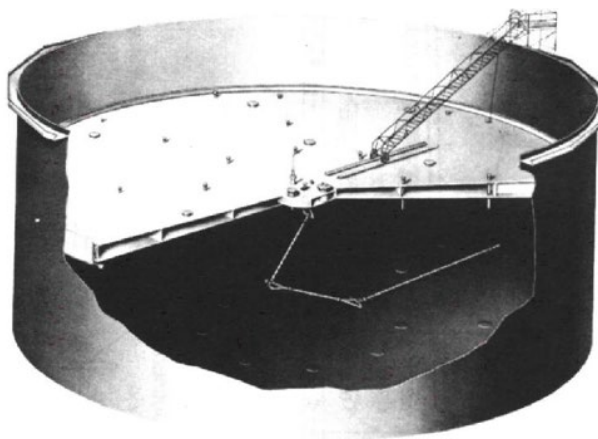


Figure 7—Double-deck Floating-roof Tank

4.2.4.1.4 Floating-roof Seals

Cross-sectional sketches showing important features of floating roofs are shown in Figure 8. Floating-roof sealing systems are used to seal the space between the tank wall and the floating roof. When a floating roof has two such devices, one mounted above the other the lower seal is the primary seal and the upper seal is the secondary seal. Primary seals may be mechanical shoe, liquid mounted, or vapor mounted. Secondary seals are rim mounted above any type of primary seal. The seal details are similar in description

for external floating-roof and internal floating-roof types, but default emission losses are unique to the floating-roof design type. API 650—Annex C external floating-roof seals and fittings will be deeper and based on results of regulatory accepted API testing have reduced default emission factors compared to API 650—Annex H internal floating-roof type seals and fittings. It is important to electrically bond the seal to ground with “grounding” shunts, cables, or other means.

4.2.4.1.5 Liquid-mounted Seals

A liquid-mounted rim seal is a resilient foam-filled or liquid-filled primary rim seal mounted in a position resulting in the bottom of the seal being normally in contact with the stored liquid surface. This seal may be a flexible foam or liquid contained in a coated fabric envelope.

4.2.4.1.6 Vapor-mounted Seals

A vapor-mounted rim seal is a peripheral seal positioned such that it does not normally contact the surface of the stored liquid. Vapor-mounted peripheral seals may include, but are not limited to, resilient foam-filled seals (similar in design to liquid-mounted seals) and flexible-wiper seals. Flexible-wiper seal means a rim seal using a blade or tip of a flexible material (such as extruded rubber or synthetic rubber; see Figure 12) with or without a reinforcing cloth or mesh.

4.2.4.1.7 Mechanical Shoe

This type of seal consists of a series of sheets (shoes) that are overlapped or joined together to form a ring and held against the tank wall by springs (or by counterweights in older designs) or other tensioning system, with a flexible vapor membrane attached between the shoe and the floating-roof outer rim. Typical examples of this type of floating-roof seal are shown in Figures 9 and 11.

4.2.4.1.8 Wiper Seals

Wiper seals are used as secondary seals. These are compression plates with wiper tips or simply an elastomeric wiper that spans the space between the floating roof and tank shell.

Figure 13 illustrates various examples of seals mounted on internal floating roofs.

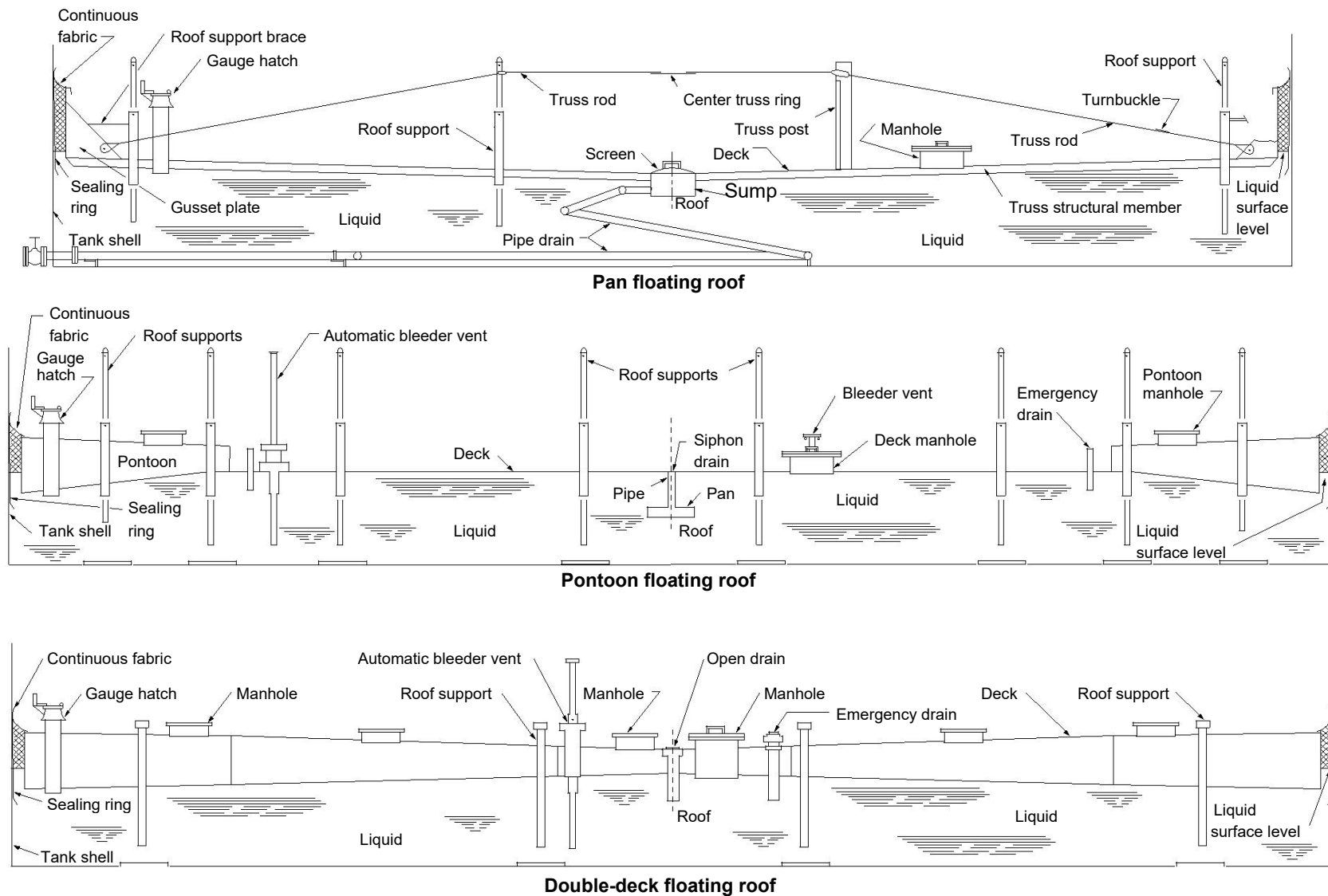


Figure 8—Cross-section Sketches of External Floating-roof Tanks Showing the Most Important Features

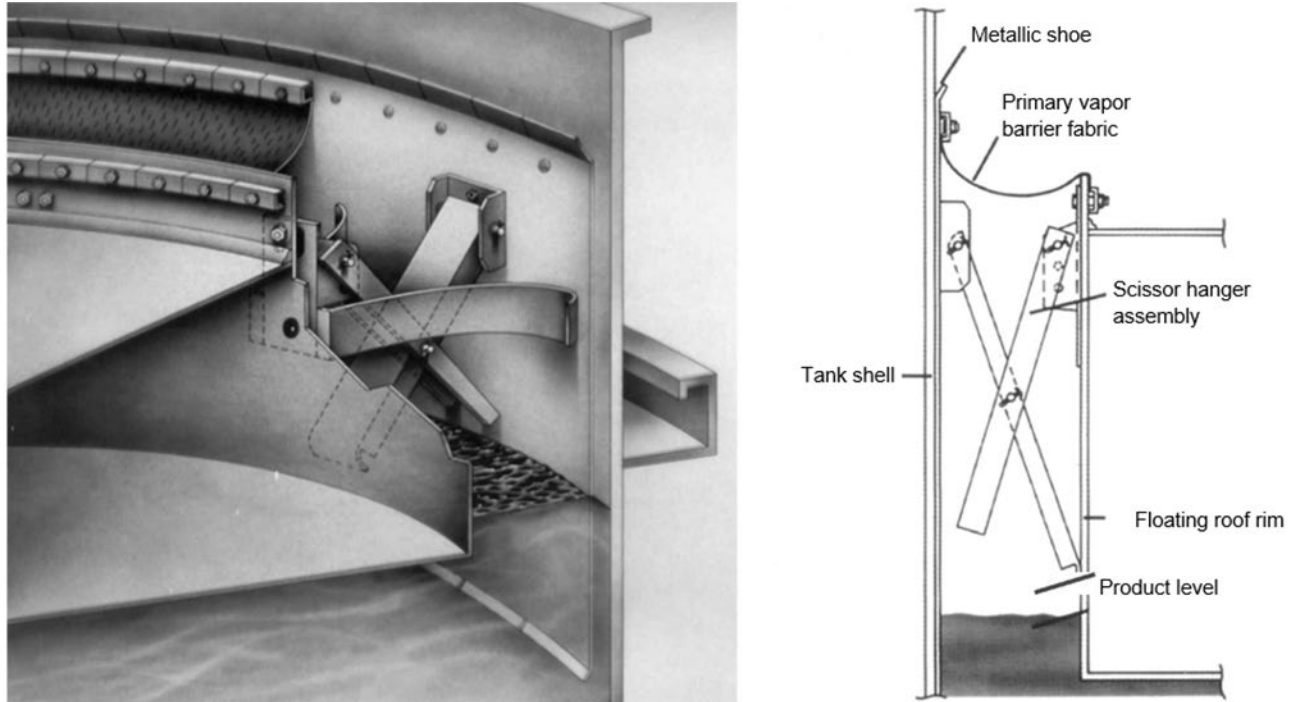
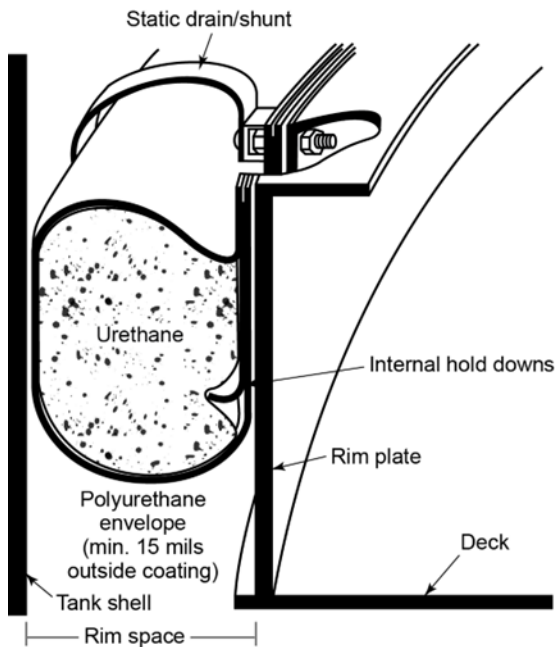
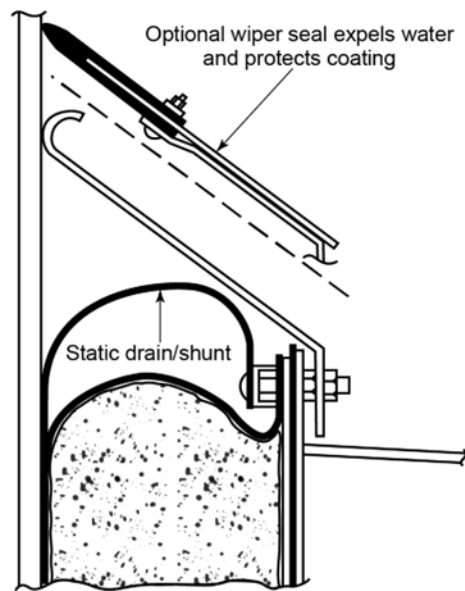


Figure 9—Floating-roof Shoe Seal



Cross-Section Foam Seal for Steel Floating Roof



Cross-Section Foam Seal in Hand Floating Roof with Standard Weather Shield for Longer Seal Life

Figure 10—Floating-roof Log Seal

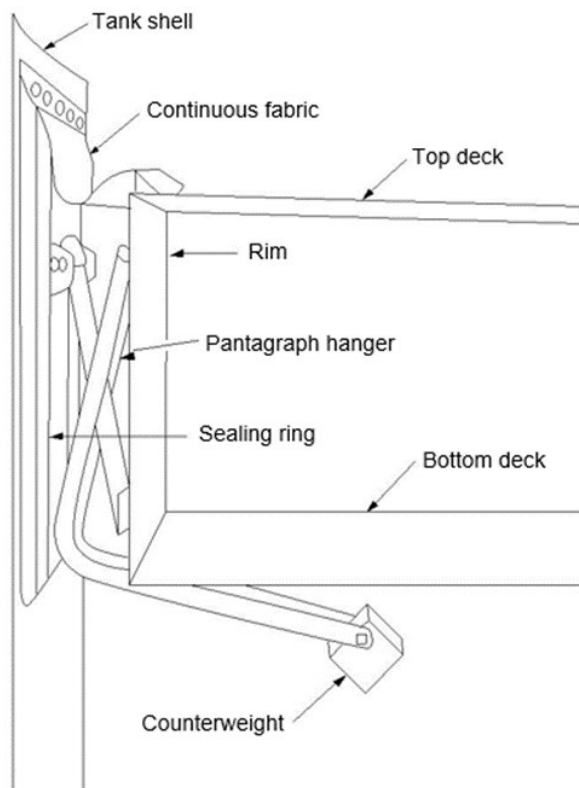


Figure 11—Floating Roof Using Counterweights to Maintain Seal

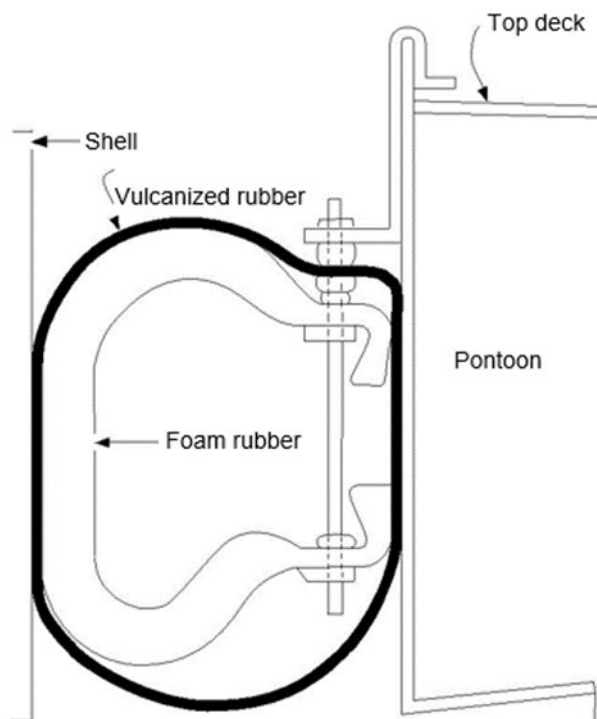


Figure 12—Floating Roof Using Resilient Tube-type Seal

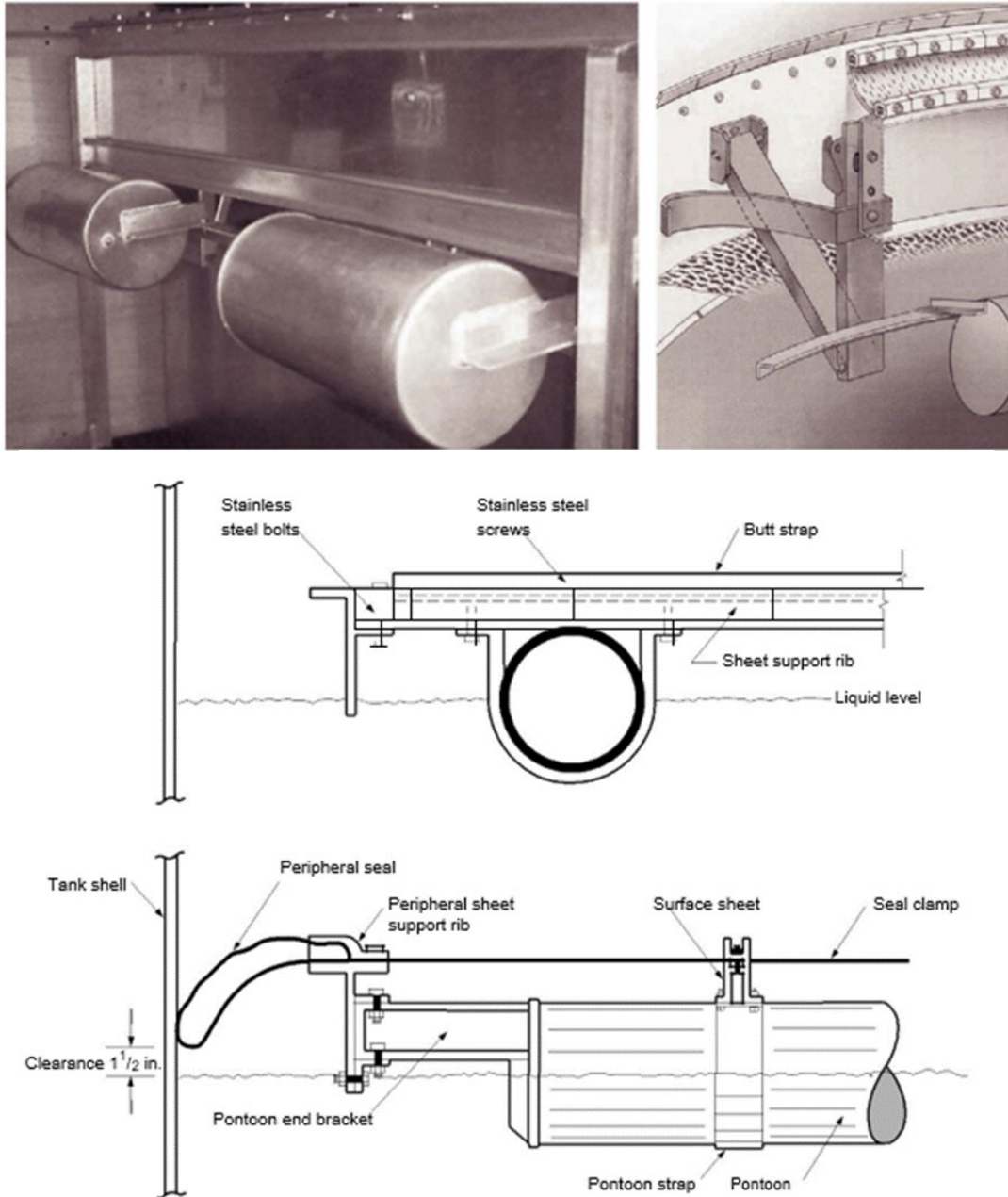
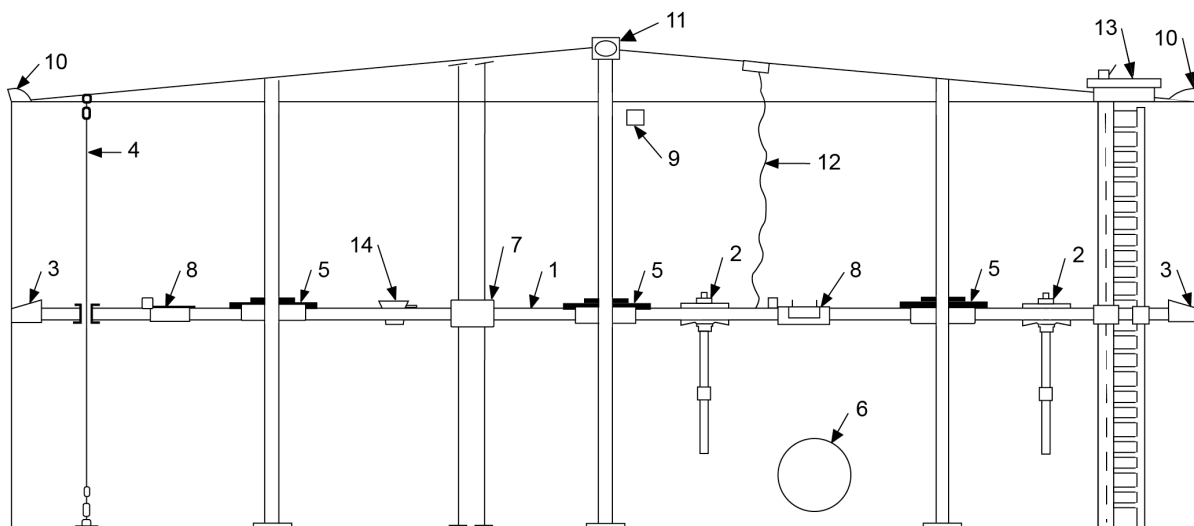


Figure 13—Typical Arrangement for Metallic Float Internal Floating-roof Seals

4.2.4.2 Internal Floating-roof Tanks

Another type of tank has both a fixed roof and an internal floating roof. Internal floating roofs can be of full contact or non-contact design. The fixed roof is usually a supported cone or dome (of steel or aluminum). The internal floating roof (shown in Figure 14) can be constructed of steel, aluminum, or other material. An existing external floating roof can be covered with a steel cone roof, or geodesic dome. When the external floating roof is covered, it functions much as it did as an external floating roof. Modifications may be made to the roof drain system as the roof is no longer exposed to the elements and many owner-operators choose to remove or modify the rolling access ladder. Such tanks are usually built to alleviate weather-related concerns about the flotation of an external floating roof, to reduce vapor emissions, or to prevent product contamination. An existing fixed-roof tank often can be modified by the installation of an internal floating roof. Cone roofs with an internal floating roof supported by cables suspended from the fixed cone roof are

another common design that is being used (see Figure 15). Internal floating roofs are also made of aluminum, and these can be of the “skin and pontoon” design where the floating roof rests on the pontoons that are immersed in the product or these may also be of full contact design, similar to a steel internal floating roof.



Key

- | | | | |
|---|---------------------------|----|----------------------|
| 1 | deck | 8 | vacuum relief device |
| 2 | support legs | 9 | overflow vent |
| 3 | seal | 10 | peripheral roof vent |
| 4 | anti-rotation device | 11 | center roof vent |
| 5 | column negotiating device | 12 | antistatic grounding |
| 6 | manway | 13 | roof hatch |
| 7 | gauge floatwell | 14 | gauge funnel |

Figure 14—Typical Internal Floating-roof Components

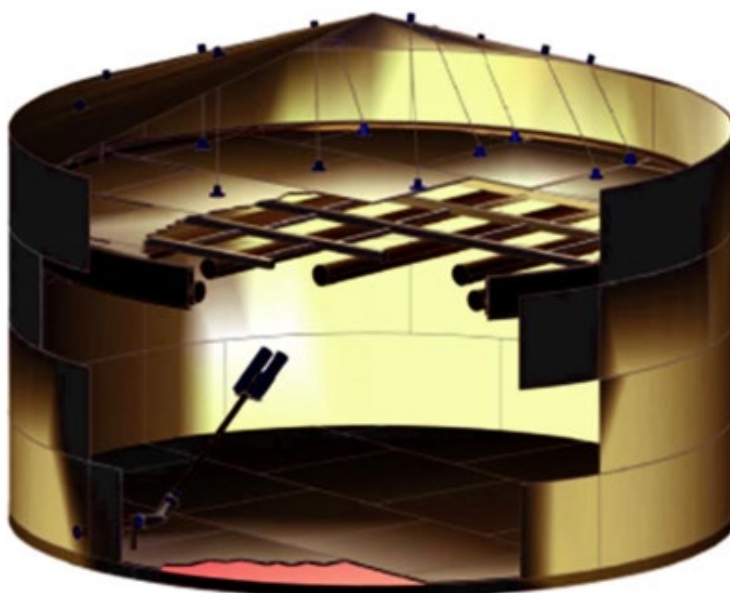


Figure 15—Cable-supported Internal Floating-roof Tank

API 650—Annex H classifies internal floating roofs into the following types.

- a) Metallic pan internal floating roofs have a peripheral rim above the liquid for buoyancy. These roofs are in full contact with the liquid surface and are typically constructed of steel. See Figure 5. **Caution—These are no longer permitted for construction, but many are still in use. These types have no closed buoyancy compartments and are *not* considered a floating roof for purposes of AST spacing in accordance with NFPA 30.**
- b) Metallic open-top bulk-headed internal floating roofs have peripheral open-top bulk-headed compartments for buoyancy. These roofs are in full contact with the liquid surface and are typically constructed of steel. These types have no closed buoyancy compartments and are *not* considered a floating roof for purposes of AST spacing in accordance with NFPA 30.
- c) Metallic pontoon internal floating roofs have peripheral closed-top bulk-headed compartments for buoyancy. These roofs are in full contact with the liquid surface and are typically constructed of steel.
- d) Metallic double-deck internal floating roofs have continuous closed top and bottom decks that contain bulk-headed compartments for buoyancy. These roofs are in full contact with the liquid surface and are typically constructed of steel.
- e) Metallic internal floating roofs on floats have their deck above the liquid, supported by closed pontoon compartments for buoyancy. These roof decks are not in full contact with the liquid surface and are typically constructed of aluminum alloys or stainless steel.
- f) Metallic sandwich-panel/composite internal floating roofs have metallic composite material panel modules for buoyancy compartments. Panel modules may include a honeycomb or closed cell foam core; however, cell walls within the panel module are not considered “compartments” for purposes of inspection and design buoyancy requirements. These roofs are in full contact with the liquid surface and are typically constructed of aluminum alloys or purchaser-approved composite materials.
- g) Hybrid internal floating roofs shall, upon agreement between the purchaser and the manufacturer, be a design combination of roof types having bulk-headed compartments with closed-top perimeter pontoon and open-top center compartments for buoyancy. These roofs are in full contact with the liquid surface and are typically constructed of steel.
- h) Other roof materials or designs if specified and described in detail by the purchaser.

4.2.5 Vapor Recovery Systems

Vapor recovery systems can be provided on several types of tanks, such as a fixed cone roof (see Figure 1), umbrella roofs (see Figure 3), and vapor dome roofs (see Figure C.9). Adjustment in relief valve settings will be required to accommodate the operating parameters for the vapor recovery system. The tank must be designed for the internal and external (vacuum) pressures with relief vents having operating pressure set to fully open within the design pressure limits of the tank.

4.3 Low-pressure Storage Tanks

4.3.1 Construction, Materials, and Design Standards

Low-pressure storage tanks are those designed to operate with pressures in their gas or vapor spaces exceeding the 2.5 psi (18 kPa) gauge permissible in API 650 but not exceeding the 15 psi (103 kPa) gauge maximum limitation of API 620. These tanks are generally constructed of carbon or alloy steel and are usually welded, although riveted tanks in low-pressure service are still found. Rules for the design and construction of large, welded, low-pressure storage tanks are included in API 620. Venting requirements are covered in API 2000.

API 625 addresses tank systems designed for storing refrigerated liquefied gas. A tank system consists of one or more containers together with various accessories, appurtenances, and insulation. The metal storage containers themselves are addressed in API 620—Annex R for steel containers for refrigerated products from 40 °F (4 °C) to –60 °F (–51 °C) and in API 620—Annex Q for steel containers for –60 °F (–51 °C) to –325 °F (–198 °C). ACI 376 addresses concrete containers for 40 °F (4 °C) to –270 °F (–168 °C).

4.3.2 Use of Low-pressure Storage Tanks

Low-pressure storage tanks are used for the storage of the more volatile fluids having a true vapor pressure exceeding the pressure limits of API 650 but not more than 15 psi (103 kPa) gauge. Light crude oil, gasoline blending stock, light naphtha, pentane, volatile chemicals, liquefied petroleum gas, liquefied natural gas, liquid oxygen, and liquid nitrogen are examples of liquids that should be stored in low-pressure storage tanks.

API 620—Annexes R and Q and ACI 376 provide single-wall and double-wall construction details.

4.3.3 Types of Low-pressure Storage Tanks

Tanks that have cylindrical shells and cone or dome roofs are typically used for pressures less than about 5 psi (34.5 kPa) gauge. Tank bottoms may be flat or have a shape similar to the roof. Hold-down anchorage of the shell is generally required. For pressures above about 5 psi gauge (34.5 kPa) gauge, hemispheroid, spheroid, and noded spheroid tank types are commonly used. Tanks for this application are now typically constructed as spheres. Such tanks are designed to withstand the vapor pressure that may be developed within a tank having no devices or means to change or relieve the internal volume. As with atmospheric storage tanks, these tanks are provided with relief valves to prevent pressures from rising above design values.

Spheres are also constructed for product under pressure in accordance with API 620.

4.3.4 Tank Systems for Refrigerated, Liquefied Gas Storage

API 625—Section 5 defines and describes various storage concepts for refrigerated liquefied gas tank systems. These include single, double, and full containment concepts. Some of these concepts are briefly described as follows.

Single containment—This system incorporates a liquid-tight container and a vapor-tight container. There are several variants to the single containment concept such as the following.

- 1) Single wall—Single low-temperature steel or concrete tank containing the cold liquid with warm vapor-containing roof, suspended deck with insulation, and external wall insulation. (See API 625—Figure 5.1.)
- 2) Single wall—Single low-temperature steel or concrete tank containing the cold liquid with low-temperature vapor-containing roof, external roof insulation, and external wall insulation. (See API 625—Figure 5.2.)
- 3) Double wall—Single low-temperature steel or concrete tank containing the cold liquid with a warm vapor-containing roof, suspended deck with insulation, annular space insulation, and warm vapor-containing outer tank (concrete or steel). (See API 625—Figure 5.3.)
- 4) Double wall—Single low-temperature steel or concrete tank containing the cold liquid with low-temperature vapor-containing roof, external roof insulation, annular space insulation, and warm vapor-containing outer tank (concrete or steel). (See API 625—Figure 5.4.)

Double containment—An inner tank (low-temperature steel or concrete) containing the cold liquid surrounded by a secondary containment tank of steel or concrete that holds any leaked liquid but not any leaked vapor. There are several variants to the double containment concept such as the following.

- Low-temperature steel or concrete primary liquid container, secondary low-temperature steel or concrete secondary liquid container, suspended deck with insulation, warm vapor-containing roof, and insulation on primary liquid container shell. (See API 625—Figure 5.5.)

Full containment—An inner tank (low-temperature steel or concrete) containing the cold liquid surrounded by a secondary containment tank of steel or concrete that holds any leaked liquid and provides for a controlled release of vapor. There are several variants to the full containment concept as follows.

- 1) Low-temperature steel or concrete primary liquid container, secondary low-temperature steel or concrete secondary liquid container, suspended deck with insulation, warm vapor-containing roof, and annular space insulation between the liquid containers. (See API 625—Figure 5.7.)
- 2) Concrete primary liquid container, concrete secondary containment, and concrete roof. (See API 625—Figure 5.10.)

5 Reasons for Inspection and Causes of Deterioration

5.1 Reasons for Inspection

5.1.1 General

The basic reasons for inspection are to determine the physical condition of the tank and to determine the type, rate, and causes of damage mechanisms and associated deterioration. This information should be carefully documented during each inspection (see Section 11 for a list of example documentation). The information and data gained from an inspection contribute to the planning of future inspections, repairs, and replacement and yield a history that should form the basis of good quality permanent inspection records.

5.1.2 Process Safety and Environmental Protection

One of the primary reasons to conduct periodic scheduled inspections is to identify deficiencies that could result in a process safety incident, such as loss of containment, which could lead to fire, toxic exposure, or other environmental hazards. These deficiencies should be addressed as soon as practical through evaluation, further inspection, or repair.

5.1.3 Regulatory Requirements

5.1.3.1 General

In general, regulatory agencies require the compliance with an industry standard or code or adherence to Recognized and Generally Accepted Good Engineering Practices (RAGAGEP) when performing any inspection and repair activities. Many regulatory groups, including the Occupational Safety and Health Administration (OSHA) and the Pipeline and Hazardous Materials Safety Administration (PHMSA) in the United States, require that operating companies follow internal procedures in addition to applicable codes and standards (which is especially important if internal procedures require more than applicable codes and standards).

5.1.3.2 Regulatory

API 653 was developed to provide an industry standard for the inspection of aboveground storage tanks. It has been adopted by a number of regulatory and jurisdictional authorities.

Internal procedures regarding inspection of tanks should encompass the requirements outlined in API 653 to help ensure compliance with many of the regulatory and jurisdictional authorities. Owner-operators should be familiar with the regulatory requirements, including which standards and editions are recognized by their regulatory agencies, as the latest edition of the standard is not always the one referenced.

5.1.3.3 Emissions Control

In the United States, the Environmental Protection Agency has issued a Spill Prevention, Control, and Countermeasure rule that covers most petroleum storage facilities. These regulations allow tank owners and operators to use industry standards and practices to implement and ensure an effective storage tank integrity program. Currently, the most widely recognized tank inspection standards are API 653, API 12R1, STI SP001, and, in Europe and the United Kingdom, EEMUA 159.

Regulatory requirements for emission sources (such as floating-roof designs, floating-roof seals, and tank vents) should be considered when establishing the inspection plans for tanks, as some environmental regulations require shorter intervals than those stipulated by API 653. In some cases, more frequent inspections or additional inspections of some emission sources are required.

5.1.3.4 Mechanical Integrity and Reliability

Inspections are an important part of avoiding failures, maintaining safety, and optimizing availability. Therefore, it is prudent to take a proactive approach toward storage tank inspection and maintenance to ensure continued integrity and reliability of the assets.

5.1.3.5 Tank Calibration

Tanks are calibrated for inventory and record reference; this is done upon construction and at future intervals to coincide with API 653 out-of-service inspections. There may be need for more frequent calibration records to meet Custody Transfer Requirements and US Customs Regulations. There are requirements and options to consider for external AST calibration. See API *MPMS* Ch. 2 for AST calibration requirements and options. With use of 3D imagery, this provides additional information for the AST inspector and integrity specialist (allowing information for future modification and tracking of changes over time).

5.2 Deterioration of Tanks

5.2.1 General

Corrosion is the prime cause for the deterioration of steel storage tanks and accessories. Locating and measuring the extent of corrosion is a major reason for storage tank inspection. If left unchecked, tank deterioration can progressively lead to failure, which may have adverse effects such as endangering personnel or the public, environmental and property damage, and business interruptions or damage to reputation.

5.2.2 External Corrosion

5.2.2.1 Atmospheric Corrosion

Atmospheric corrosion can occur on all metallic tank components exposed to the atmosphere. The type of tank, construction details, and environmental conditions can all affect the location, extent, and severity of external corrosion. For example, a sulfurous, acidic, or marine atmosphere can damage protective coatings and increase the rate of corrosion. External surfaces of the tank and auxiliary equipment will corrode more rapidly if they are not protected with coatings where surfaces are in contact with moisture or the ground. Extended contact with water is likely to cause localized corrosion. Such susceptible areas should be protected with coatings designed to withstand long-term immersion, or the owner-operator should consider alternative mitigation strategies. Inspections should target areas where tank construction details cause water or sediment to accumulate. For further information on atmospheric corrosion, refer to API 571.

5.2.2.2 Tank Bottoms

External corrosion of tank bottoms can be significant. Refer to API 650—Annex B “Recommendations for Design and Construction of Foundations for Aboveground Oil Storage Tanks” and Annex I “Undertank Leak Detection and Subgrade Protection” containing some optional details for tank bottom leak detection and

corrosion protection. Refer to API 651 for optional cathodic protection design, and see API 655 for information on use of optional VCIs for soil-side corrosion protection (beneath AST bottoms). The foundation material used for forming a pad that is directly in contact with the steel bottom plates can contain materials that promote corrosion. For example, cinder is known to contain sulfur compounds that become very corrosive in the presence of moisture. The presence of clay, wood, gravel, or crushed stone as contaminants in a sand pad can cause pitting corrosion at each point of contact. Faulty pad preparation or poor drainage can allow water to remain in contact with the tank bottom. If a tank previously leaked corrosive fluid through its bottom, accumulation of the fluid underneath the tank can cause external corrosion of the bottom plates. For tanks that are supported above grade, an improperly sealed ringwall can allow moisture to accumulate between the tank and the support, thereby accelerating corrosion. A storage tank engineer should determine if the sealing design is appropriate and recommend the most appropriate design, which may include removal of the existing sealant. Any failing sealant that will remain should be repaired or removed. Asphalt-impregnated fiberboard is not a recommended sealant for tanks sitting on concrete ringwall foundations, as the fiberboard deteriorates and gaps are known to develop over time. For further information on sealing the bottom edge projection to the foundation, refer to API 654. The lower tank shell can be exposed to accelerated external corrosion near the grade line where soil movement has raised the grade level to cover the lower portion of the shell. Containment areas should be drained as soon as possible after water accumulates to minimize the possibility of bottom or lower shell corrosion. For further information on soil corrosion, refer to API 571.

5.2.2.3 Corrosion Under Insulation

External corrosion also occurs when insulation absorbs ground or surface water by wicking action or when damaged or improperly sealed openings around nozzles, roof-to-shell joint and attachments (including roof insulation at the perimeter where it meets the shell) allow water behind insulation. For further information on CUI, refer to API 571 and API 583. In cases where the wall of the tank is partially below grade, the inspector should pay special attention at the soil interface for accelerated corrosion.

5.2.2.4 Riveted Tanks

Riveted tanks are becoming increasingly rare in refinery and petrochemical plant operations; however, many riveted tanks are still in service and are included in inspection plans. API 650 does not provide guidance for the construction of riveted tanks.

Riveted tanks typically were constructed in accordance with API 12A, which has been withdrawn from publication. Other design and construction standards should also be referenced. Riveted tanks have many niches where concentration cell corrosion can occur (see 8.3.9.7). Leaks at the seams of riveted tanks can cause failure of external coatings, allowing external corrosion to develop.

5.2.3 Internal Corrosion/Deterioration

5.2.3.1 General

The occurrence of internal corrosion in a storage tank depends on the contents of the tank and its materials of construction. API 571 is a primary resource document for damage mechanisms and should be consulted when developing the inspection plan to ensure that proper inspection and examination techniques are applied. Annex A provides information on the more common NDE methods.

5.2.3.2 Product/Vapor/Sludge and Water Corrosion

Crude oil and petroleum product tanks are usually constructed of carbon steel. Internal corrosion of these tanks in the vapor space (i.e. above the liquid level) can be caused by hydrogen sulfide vapor, water vapor, oxygen, or any combination of these. In the areas in contact with the stored liquid, corrosion is commonly caused by acid salts, hydrogen sulfide or other sulfur compounds, dew point corrosion, or contaminated water that settles out and mixes with solids on the bottom of the tank, typically referred to as bottom

sediment and water (BS&W). The salts and water in BS&W can serve as an electrolyte to facilitate electro-chemical corrosion on the top surface of the bottom. Sludge from sulfur containing crude and other high sulfur service applications can become anaerobic and mesophilic anaerobic microbes will convert sulfur to hydrogen sulfide, which when exposed to water will produce sulfuric acid (a strong electrolyte) that will facilitate loss of exposed steel. Microbial induced corrosion (MIC) does not directly corrode but induces the production of chemicals which facilitate electro-chemical corrosion. Use of dissimilar metals submerged within the electrolyte must be avoided. Issues of SCC can be of particular concern when the product is known to be corrosive to welds and other heat-affected zones. Ethanol, diethanolamine, and caustic products are just a few of the products that can contribute to this condition when in contact with bare metal. When storing biofuels and biofuel feedstocks, especially at elevated temperatures, the presence of free fatty acids and water at varying concentrations found not only in the product, but also in the vapor space, can lead to severe corrosion of the tank shell, roof structure and cone roof underside.

5.2.3.3 Linings

In some cases, it is necessary to use linings (see API 652) that are more resistant to the stored fluid than are the materials of construction. In some particularly corrosive services, it may be necessary to construct the tank with materials that are more compatible with the service environment, such as aluminum, stainless steels, or other alloys. These materials can experience deterioration from less common mechanisms, such as caustic or chloride SCC, acid erosion, flow erosion, electrolytic reactions, and cyclic fatigue, among others.

5.3 Leaks, Cracks, and Mechanical Deterioration

5.3.1 General

Storage tanks should be inspected for leaks (current or imminent) or defects to minimize or prevent loss, hazard to personnel, pollution of air, ground water, and waterways, and damage to other equipment.

5.3.2 Brittle Fracture

Brittle fracture and sudden loss of the contents of a tank can result in injuries to personnel and extensive damage to equipment in surrounding areas. Pollution of streams or waterways can result when such a tank failure occurs near a waterway or is connected to one by a sewer or other flow channel. Figure 17 illustrates the complete loss of a tank from brittle fracture. Proper design, fabrication, operation, and maintenance will minimize the probability of brittle fracture. A detailed discussion of brittle fracture can be found in API 571. API 653—Section 5.3 provides a procedure to assess the risk of tank failure due to brittle fracture and guidance for lowering the risk of brittle fracture. Brittle fracture is not a concern for nonwelded API 12B factory-coated bolted tanks.

5.3.3 Leaks

Leaks are primarily the result of corrosion but can occur at improperly welded joints, at riveted joints, at pipe thread or gasket connections or cover plates, or at crack-like flaws (including arc strikes on plates) in welds or in plate material. Three-plate laps in lap-welded tank bottoms are particularly prone to defects that can lead to leaks.

5.3.4 Cracks

Crack-like flaws can result from a number of causes including deficiencies in design, fabrication, and maintenance. The most likely points for crack-like flaws to occur are at the bottom-to-shell details, around nozzle connections, at manholes, around rivet holes or around rivet heads, at welded brackets or supports, drain dry connections, and at welded seams. The lower shell-to-sketch plate or shell-to-bottom weld is especially critical because in relatively large or relatively hot tanks there is a higher likelihood for this detail to develop a crack-like flaw due to high stresses. Potential for this occurrence can be minimized by the use

of thicker, butt-welded annular bottom plates, which are required by API 650 for higher design stress tanks and for larger elevated temperature tanks (see API 650, Sections 5.5 and M.4.1, respectively). Photographs of typical crack-like flaws in tanks are shown in Figure 16, Figure 18, and Figure 19. Other cracking mechanisms are possible, including SCC. All cracking mechanisms are discussed further in API 571.



Figure 16—Cracks in Tank Shell Plate



Figure 17—Extensive Destruction from Instantaneous Failure

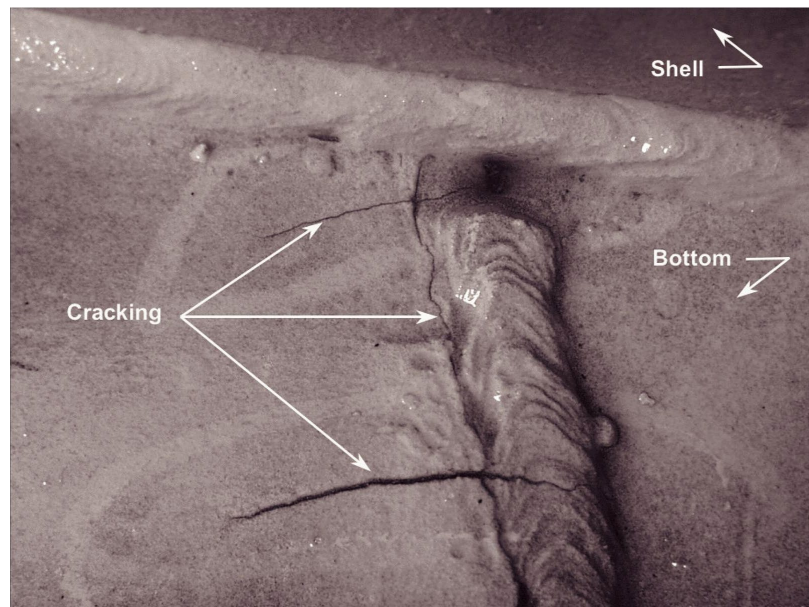


Figure 18—Cracks in Bottom Plate Welds Near the Shell-to-bottom Joint

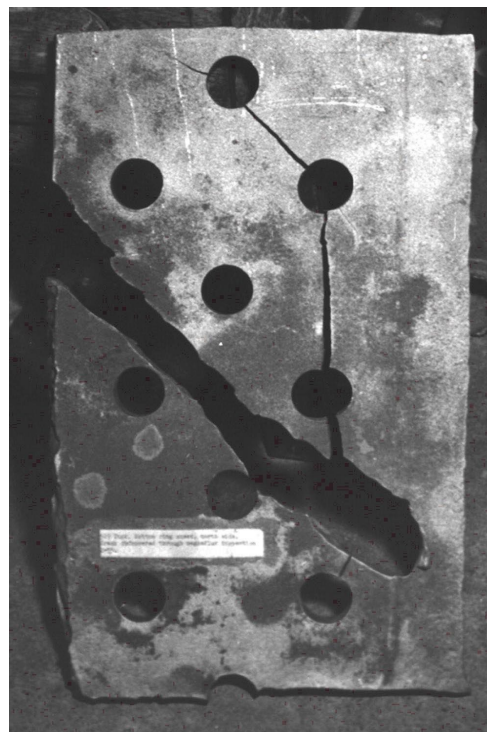


Figure 19—Cracks in Tank at Riveted Lap Joint to Tank Shell

5.3.5 Mechanical Deterioration

Many other types of mechanical deterioration can develop over the service life of a storage tank. If such deterioration is discovered early through inspection, continued deterioration can be minimized and potential failures and leaks can be prevented. Early detection of deterioration and conditions that cause deterioration permit cost-effective maintenance and repair to be done on a scheduled basis, minimizing the risk of failure. Examples of conditions that cause other types of mechanical deterioration can include severe service

conditions, such as frequent fill/withdrawal cycling or elevated temperature (see API 650—Annex M) affecting the integrity of the shell-to-bottom weld, bulging, peaking, denting, overpressure, etc.

5.3.6 Settlement

Settlement of a tank due to soil movement under the tank or tank foundation can also cause mechanical deterioration. Uniform settlement of the entire tank would not necessarily cause structural damage or be considered a serious issue. Large or uneven amounts of settlement can cause nozzles with attached piping to become overstressed and possibly deformed or cracked or interfere with the normal operation of a floating roof. Significant amounts of uneven settlement should be cause for concern and for further investigation. Edge settlement in tanks with cone-down bottoms can trap BS&W, resulting in bottom and lower shell corrosion in this area. Soil and water can also be retained against the external shell when such settlement is present. Refer to API 653 for guidance on conducting settlement surveys.

5.4 Deterioration and Failure of Auxiliary Equipment

5.4.1 Tank Roof Equipment

Pressure/vacuum vents and flame arrestors can fail to operate for the following reasons:

- a) the presence of fouling material or debris;
- b) corrosion between moving parts and guides or seats;
- c) deposit of foreign substances by birds or insects;
- d) formation of ice;
- e) accumulation of grit-blasting material;
- f) the covering of the vent opening with plastic or the plugging of vent openings with paint during coating operations that is not subsequently removed;
- g) tampering by unauthorized personnel;
- h) improper setting of the pressure relief actuation set point or vacuum relief actuation set point.

Examination of tank venting devices should be included in a periodic inspection to ensure that their proper operation and protection are maintained. API 576 provides information regarding inspection of pressure-relieving devices and, specifically, weight-loaded pressure/vacuum relief devices.

5.4.2 Internal Equipment

Gauge float leakage can be caused by corrosion or cracking. Inoperative pulleys, bent or broken float tapes, or plugged guides can cause float-type gauging devices to become inoperative.

Equipment for draining water from floating roofs can be rendered inoperable by plugging or by mechanical damage caused by debris, ice, or rotation of the floating roof. Drain piping, mechanical joints, and hoses can develop leaks that will allow the tank contents either to leak from the roof drain system or allow water to flow into the tank. For single-deck floating roofs, leakage of the tank contents onto the floating roof can submerge or sink the roof. Inoperative drains with installed plugs (or with closed valves) can cause enough rain water to accumulate on the roof to sink a pontoon-type floating roof.

Heating systems inspections should take into consideration programs that address the specific types of equipment that are included (e.g. steam systems inspections should consider API 570 and API 574; bundle inspections should consider API 510 and API 572).

5.4.3 Shell Attachments

Deterioration of auxiliary equipment—such as ladders, stairways, platforms, wind girders, and shell stiffeners—can occur from corrosion, wind, and other external forces. Mechanical equipment, such as mixers, swing line pontoons, piping and swing joints, diffusers, jet nozzles and other flow direction details, baffles, rakes, and agitators, can suffer from deterioration due to corrosion, wear from flow erosion, and mechanical defects.

5.4.4 Miscellaneous

API 653—Annex C includes inspection checklists for many types of deterioration of storage tank auxiliary equipment and other appurtenances. The tank inspector should be thoroughly familiar with these checklists.

6 Inspection Plans

6.1 General

6.1.1 Developing Inspection Plans

An inspection plan is often developed and implemented for tanks within the scope of API 653 through the collaborative work of the inspector, engineer, corrosion specialist, and operations personnel. An inspection plan should contain the inspection tasks, scope of inspection, and schedule required to monitor damage mechanisms and ensure the mechanical integrity of the tank. Knowledge of the capabilities and limitations of NDE techniques allows the proper choice of examination technique(s) to identify particular damage mechanism in specific locations. The plan should typically:

- a) define the type(s) of inspection needed (e.g. external, internal, thickness measurements, NDE, associated piping, etc.);
- b) identify the regulatory intervals for seal or other component inspection needs, any applicable jurisdictional requirement, and the date for each inspection type;
- c) describe the inspection and NDE techniques, extent, and locations;
- d) describe any surface cleaning requirements needed for inspection and examinations;
- e) describe the requirements of any needed pressure or tightness test (e.g. type of test, test pressure, and duration);
- f) describe any required repairs.

6.1.2 Incorporating Operations Information in Inspection Plans

Inspection plans should consider information such as operating temperature ranges, process fluid corrosive contaminant levels, material of construction, tank design and configuration, service changes since the last inspection, and inspection/maintenance history. Ongoing communication with operating personnel when process changes or upsets occur that could affect damage mechanisms and rates are critical to keeping an inspection plan updated. Other common issues in an inspection plan include the following:

- describing the types of damage mechanisms anticipated or experienced in the tank;
- defining the location of the damage;
- defining any special access requirements.