May 2001

Process Industry Practices
Vessels

PIP VECTA001
Tank Selection Guide

PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

In an effort to minimize the cost of process industry facilities, this Practice has been prepared from the technical requirements in the existing standards of major industrial users, contractors, or standards organizations. By harmonizing these technical requirements into a single set of Practices, administrative, application, and engineering costs to both the purchaser and the manufacturer should be reduced. While this Practice is expected to incorporate the majority of requirements of most users, individual applications may involve requirements that will be appended to and take precedence over this Practice. Determinations concerning fitness for purpose and particular matters or application of the Practice to particular project or engineering situations should not be made solely on information contained in these materials. The use of trade names from time to time should not be viewed as an expression of preference but rather recognized as normal usage in the trade. Other brands having the same specifications are equally correct and may be substituted for those named. All Practices or guidelines are intended to be consistent with applicable laws and regulations including OSHA requirements. To the extent these Practices or guidelines should conflict with OSHA or other applicable laws or regulations, such laws or regulations must be followed. Consult an appropriate professional before applying or acting on any material contained in or suggested by the Practice.

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Table of Contents

1. Introduction

1.1 Purpose

This Practice provides information to assist engineers in the selection and specification of aboveground storage tanks.

1.2 Scope

This Practice covers storage of liquid products at design pressures from atmospheric to 15 psig for refineries, chemical plants, pipeline locations, marketing and distribution terminals, and production facilities. It provides guidance in avoiding recurring problems and indicates preferred practices where appropriate. Although intended primarily for carbon steel tanks, most of the factors discussed are applicable regardless of the material of construction.

Requirements for specifying and supplying *API 650* tanks are defined in *PIP VESTA002*.

2. References

Applicable requirements in latest edition (or edition indicated) of the following industry codes and standards shall be considered an integral part of this Practice. Short titles will be used herein when appropriate.

2.1 Process Industry Practices (PIP)

– VEDTA003 - *Atmospheric Storage Tank Data Sheet and Instructions (in Accordance with API Standard 650*)

– VESFG001 - *Fiberglass Tank and Vessel Selection, Design, and Fabrication Specification, ASME RTP-1 and Section X*

– VESLP001 - *Specification for Low-Pressure, Welded Shop-Fabricated Vessels*

– VESTA002 - *Atmospheric Storage Tank Specification (in Accordance with API Standard 650*)

2.2 Industry Codes, Standards, Recommended Practices, and Bulletins

- American Petroleum Institute (API)
  – ANSI/API 12B - Specification for Bolted Tanks for Storage of Production Liquids
  – ANSI/API 12D - *Specification for Field Welded Tanks for Storage of Production Liquids*
  – ANSI/API 12F - *Specification for Shop Welded Tanks for Storage of Production Liquids*
  – ANSI/API 12P - *Specification for Fiberglass Reinforced Plastic Tanks*
  – ANSI/API 575 - *Inspection of Atmospheric and Low-Pressure Storage Tanks*

- API 620 - *Design and Construction of Large, Welded, Low-Pressure Storage Tanks*
- API 12C - *API Specification for Welded Oil Storage Tanks*
- API 650 - *Welded Steel Tanks for Oil Storage*
- ANSI/API 652 - *Lining of Aboveground Petroleum Storage Tank Bottoms*
- API 653 - *Tank Inspection, Repair, Alteration, and Reconstruction*
- API 2000 - *Venting Atmospheric and Low-Pressure Storage Tanks Nonrefrigerated and Refrigerated*
- API 2003 - *Protection against Ignitions Arising out of Static, Lightning, and Stray Currents*
- API 2516 - *Evaporation Loss from Low-Pressure Tan*ks
- API 2517 - *Evaporation Loss from External Floating-Roof Tanks*
- API 2518 - *Evaporation Loss from Fixed-Roof Tanks*
- API 2519 - *Evaporation Loss from Internal Floating-Roof Tanks*

• American Society of Mechanical Engineers (ASME)

RTP-1 - *Reinforced Thermoset Plastic Corrosion Resistant Equipment*

- B96.1 - *Welded Aluminum Storage Tanks*
- *ASME Boiler and Pressure Vessel Code*
  - *Section VIII, Division 1 - Rules for Construction of Pressure Vessels*
  - *Section X - Fiber-Reinforced Plastic Pressure Vessels*

• American Society for Testing and Materials (ASTM)

- D 3299-00 - *Standard Specification for Filament-Wound Glass-Fiber-Reinforced Thermoset Resin Corrosion-Resistant Tanks*
- D4097–95aε3 - *Standard Specification for Contact-Molded Glass-Fiber-Reinforced Thermoset Resin Corrosion-Resistant Tanks*

• American Water Works Association (AWWA)

- D100 - *Welded Steel Tanks for Water Storage*

• National Association of Corrosion Engineers (NACE)

- RP0178 - *Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to Be Lined for Immersion*
- RP0294 - *Design, Fabrication, and Inspection of Tanks for the Storage of Concentrated Sulfuric Acid and Oleum at Ambient Temperatures*

• National Fire Protection Association (NFPA)

- NFPA 11 - *Standard for Low Expansion Foam and Combined Agent Systems*
- NFPA 15 - *Standard for Water Spray Fixed Systems for Fire Protection*
- NFPA 30 - *Standard for Flammable and Combustible Liquids Code*
- NFPA 780 - *Standard for Standard for the Installation of Lightning Protection Systems*

- Underwriters Laboratories (UL)
  – 142 - *Steel Aboveground Tanks for Flammable and Combustible Liquids*

2.3 Other Documents

– Philip Myers, *Aboveground Storage Tanks*, McGraw Hill, 1997

3. Definitions

Manufacturer - The fabricator and/or erector of the tank(s)

Purchaser - The Owner or Owner's designated agent, such as an engineering contractor

4. Selection of Tank Type

4.1 Responsibilities

4.1.1 Purchaser

The Purchaser is responsible for the following:

- Location, including specific climatic data
- Stored product information (e.g., specific gravity and vapor pressure)
- Selection of storage type and roof style
- Desired volume or overall height and diameter requirement
- Design pressure
- Maximum and minimum design metal temperature
- Selection of materials
- Connection size, style, and location
- Limits of work (e.g., foundations, piping, painting)
- Foundation, including soil investigation and design
- Corrosion allowance

4.1.2 Manufacturer

The Manufacturer is responsible for the following:

- Tank outline drawing indicating material, plate thicknesses, member sizes, etc.
- Calculations, if requested
- Other Manufacturer data required or requested by Purchaser
- Inspection and testing requirements (assigned by some standards, e.g., *API 620*, to the Purchaser)
- Providing foundations, painting, coating, lining, etc., if specified

4.2 Selection Factors

4.2.1 The following factors affect the type of tank most suitable for a specific service:

- Vapor pressure, flash point, and temperature of stored product
- Frequency of turnover (filling and emptying) and consequent value of vapor losses from filling and breathing
- Vapor control (including means of vapor recovery and conservation) required because of toxicity, value of product, air pollution restrictions, or applicable federal and local regulatory requirements
- Fire hazards, both to tank and to adjacent facilities or to property of others
- Initial capital and maintenance costs
- Corrosiveness of stored product or its vapor to material of tank construction
- Susceptibility of stored product to degradation, decomposition, or contamination from, or as influenced by, the surrounding atmosphere, the period of storage, or the materials used in tank construction
- Amount of product to be stored
- Static charge hazards
- Requirements to enable the measurement of liquid in tanks include appurtenances and strapping of the tank for the preparation of gauge tables. Appurtenances shall enable measuring the liquid level height in the tank and the average temperature of the liquid contents of the tank and shall enable obtaining average/representative sample(s) of the liquid contents of the tank and the liquid level height of any water or other foreign material that may be present.
- Inert gas blanketing facilities

4.2.2 The following API bulletins provide helpful guidance in evaluating the effect of evaporation losses and their possible influence on the type of tank required for a specific service: *API 2516*, *API 2517*, *API 2518*, and *API 2519*.

4.2.3 Where applicable, modifications of existing tanks should be considered in comparison with the purchase of new tanks. Revisions, such as the following, may often provide essential storage, vapor recovery, or vapor conservation facilities at less cost and in a shorter time.

4.2.3.1 Enlarging the roof-to-shell weld or otherwise strengthening a cone roof allows the vent valve setting to be increased.

Note: Enlarging the weld will possibly eliminate the “frangible joint” character of *API 650* tanks. Emergency vents and other safety features may have to be added. The tank Manufacturer should be consulted regarding the effect on the tank rating of enlarging this weld. Caution should also be exercised to make sure that the internal pressure is not raised high enough to lift the shell off the foundation.

4.2.3.2 A floating diaphragm may be installed in a fixed roof tank, thus preventing vapor loss or contamination.

4.2.3.3 A floating roof may be installed.

4.3 Tank Codes and Other Sources of Information

The following codes or standards, which apply to tanks, are the more commonly used documents in the process industry. Refer to Table 2.1.2 in Myers (1997) for a more complete listing of tank-related codes and standards. Refer also to *PIP VESTA002* and *PIP VEDTA003* for additional requirements applicable to tanks covered by *API 650*.

- *API 620* covers construction requirements (material, design, fabrication, erection, and testing) for large, low-pressure carbon steel, vertical, aboveground tanks with a single vertical axis of revolution. Metal temperatures not exceeding 250ºF and design pressures not exceeding 15 psig are covered. The key appendices are the following:

  Appendix C gives recommendations regarding foundations of tanks.

  Appendix K covers tank-venting devices.

  Appendix L covers seismic requirements.

  Appendix Q covers cryogenic services from -60ºF to -270ºF.

  Appendix R covers low-temperature services from +40ºF to -60ºF.

- *API 650* covers construction requirements (material, design, fabrication, erection, and testing) for large, welded, vertical cylindrical, aboveground, closed and open top welded steel storage tanks with atmospheric internal pressure up to 2-1/2 psig. The key appendices are the following:

  Appendix A provides simplified rules for tanks with thicknesses not exceeding 1/2 inch.

  Appendix B gives recommendations regarding foundations of tanks.

  Appendix C covers floating roofs.

  Appendix E provides seismic design requirements.

  Appendix F covers special designs with small internal pressures up to 2-1/2 psig.

  Appendix G gives rules for aluminum dome roofs.

  Appendix H covers internal floating roofs.

  Appendix I covers leak protection and foundation systems to protect against tank bottom leakage.

  Appendix J covers shop-built tanks not exceeding 20 feet in diameter.

Appendix M gives rules that govern when operating temperatures are between 200ºF and 500ºF (90ºC and 260ºC).

Appendix S covers stainless steel tanks.

- *API 12D* covers material, design, fabrication, and testing requirements for vertical, cylindrical, aboveground, closed top, field-welded steel storage tanks in various standard sizes (diameters of 15 feet 6 inches to 55 feet diameter) and capacities (500 to 10,000 barrels) for internal pressures approximating atmospheric, as specified.
- *API 12F* covers material, design, fabrication, and testing requirements for shop-fabricated vertical, cylindrical, aboveground, closed top, welded steel storage tanks in various standard sizes (diameters of 7 feet 11 inches to 15 feet 6 inches)and capacities (90 to 750 barrels) for internal pressures approximating atmospheric, as specified.
- *API 653* covers carbon and low-alloy steel tanks built *to API 650* and its predecessor *API 12C*. This standard provides minimum requirements for maintaining the integrity of welded or riveted, non-refrigerated, atmospheric pressure, aboveground storage tanks after they have been placed in service. It also describes the maintenance inspection, repair, alteration, relocation, and reconstruction of such tanks.
- *ASME B96.1* covers the design, materials, fabrication, erection, inspection, and testing requirements for welded aluminum-alloy, field-erected or shop-fabricated, aboveground, vertical, cylindrical, flat bottom, open or closed top tanks storing liquids under pressures approximating atmospheric pressure at ambient temperatures.
- *ASME Section VIII, Division 1*, contains mandatory requirements, specific prohibitions, and nonmandatory guidance for pressure vessel materials, design, fabrication, examination, inspection, testing, certification, and pressure relief. Vessels with operating pressures over 15 psig are within the scope of this *Code*, but lower pressures can be stamped when required by the Purchaser.
- *AWWA D100* covers the design, manufacture, and procurement of welded steel tanks for the storage of water, including reservoir tanks, standpipes, and elevated tanks.
- *UL 142* covers carbon and stainless steel atmospheric (up to 0.5 psig) horizontal and vertical tanks (in sizes from 60 gal to 50,000 gal) intended for aboveground storage of noncorrosive, stable flammable, and combustible liquids that have a specific gravity not exceeding that of water.

4.4 Types of Tanks

4.4.1 Atmospheric Storage Tanks

4.4.1.1 Fixed Roof Tanks

4.4.1.1.1 Fixed roof tanks should be used (1) for the storage of nonvolatile, low-vapor-pressure materials with true vapor pressure less than 0.75 psia at all operating conditions and

(2) in conjunction with internal floating roofs where climatic conditions prevent the use of external floating roofs alone. The allowable limit of 0.75 psia for true vapor pressure for fixed roof tanks is approximate. The user of this Practice should check the air pollution regulations for the proposed tank site to determine the actual allowable limit for the vapor pressure with fixed roof tanks. Fixed roofs may also be considered for use in storing volatile, high-vapor-pressure materials when adequate provisions for control of vapor emissions are provided.

4.4.1.1.2 If the vapor pressure of the product at maximum rundown or storage temperature is greater than or equal to 11.0 psia, a pressure storage, refrigerated storage, or vapor recovery system is required for the tank. For smaller diameter tanks, a vapor-blanketing system is sometimes used even when the vapor pressure is below 11.0 psia.

4.4.1.1.3 On smaller tanks, a fixed roof with vapor blanketing is sometimes used in lieu of a floating roof.

4.4.1.1.4 The three types of self-supporting fixed roof designs (cone, dome, and umbrella) are competitive in sizes less than 50 feet in diameter (about 15,000 barrels). Otherwise, column-supported cone roof tanks represent the least expensive storage and offer minimal maintenance.

4.4.1.1.5 Dome and umbrella roofs are often the most economical types of tanks for vapor recovery and variable vapor space conservation systems (see Section 4.4.1.5) that require pressures up to 0.5 psig.

4.4.1.1.6 Self-supporting roofs have a steeper roof and are generally found on smaller tanks.

4.4.1.1.7 *API 12D* tanks, *API 12F* tanks, and *UL 142* tanks can be purchased “off the shelf” economically in capacities up to 10,000 barrels, 500 barrels, and approximately 190 barrels, respectively.

4.4.1.1.8 *API 12B* bolted tanks can be readily assembled and disassembled without welding hazards. They are ideal for storage of as much as 10,000 barrels where requirements vary, such as on oil leases. They are subject to leaks but may be simply maintained and repaired. *API 12B* is no longer published or maintained by API and is listed here for reference only.

4.4.1.2 Floating Roof Tanks

4.4.1.2.1 This type of tank includes those having an open top, external floating roof and those having a closed top (fixed roof) with an internal roof, which floats on the surface of the stored product and are sometimes referred to as “external floaters” and “internal floaters,” respectively.

4.4.1.2.2 If the true vapor pressure of the stored product is between 0.75 psia and 11.0 psia, the tank should have a floating roof. The upper limit of 11.0 psia for true vapor pressure for floating roof tanks is approximate. The user of this Practice should check the air pollution regulations for the proposed tank site to determine the actual allowable upper limit for the vapor pressure in floating roof tanks.

4.4.1.2.3 Floating roofs with primary and secondary seals may also have an alternate vapor emission control system.

4.4.1.2.4 Internal floating roof tanks consist of a fixed roof tank with internal floating roof or deck.

4.4.1.2.5 The closed top (fixed roof) with internal floating roof design (internal floater) combines vapor control features of a floating roof with the weather protection of a fixed roof. It also provides effective insulation where products are stored at elevated temperatures. It is often competitive with the open top, pontoon-type floating roof in diameters up to 100 feet.

4.4.1.2.6 The two general types of internal floating roofs may be installed in tanks having self-supporting fixed roofs and also in tanks with a fixed roof supported by vertical columns and framing.

4.4.1.2.7 Minimum requirements for internal floating roofs are defined in Appendix H of *API 650* and *PIP VESTA002*.

4.4.1.2.8 Because internal floating roofs are not subject to the same loads as are external roofs, a wide variety of designs and materials are offered to Purchaser. Costs vary accordingly.

4.4.1.2.9 Compatibility with stored product should govern the choice of material for the basic roof and seal. For example, if caustic solutions are present, aluminum roofs should be avoided.

4.4.1.2.10 Another type of internal floating roof tank could be called a “closed floating roof tank.” This structure is similar to the above-described tank, except that it does not have the circulation vents for natural ventilation of the tank space. Instead, closed floating roof tanks rely on a pressure/vacuum vent to protect the tank from the damaging effects of over-pressure or over-vacuum. Closed floating roof tanks permit collection of emissions for further treatment if necessary.

4.4.1.3 Other Types of Tanks

In years past, atmospheric storage was sometimes handled in tanks with lifter or breather roofs or in fixed roof tanks equipped with floating membranes. By connecting tank vapor spaces, groups of tanks may be arranged in a connected group with a variable vapor space system. However, a tank shall not be connected to another via a vapor space connection if different liquids are stored and if mutual contamination or degradation can result from co-mingling vapors. No known standards address lifter or breather tanks.

The conventional gas lifter type of gas holder is becoming a rarity because of modern volume control management. No general industrial design standard exists for this kind of construction. Basic operation is that of nesting shells acting as pistons. The floating shells are loosely cylindrical and may be metallic or a flexible membrane. They are equipped with a roof-leveling system and have guided vertical motion. The roofs are typically metallic and weighted to reduce the amount of anchorage required. The two basic types are wet seal and dry seal. The wet seal type has a floating roof and shell that nest into a liquid-containing double wall seal that permits the roof portion to rise and fall as the volume changes. The dry seal type drapes a "rubber" membrane between nesting roof sections. The outer container is typically a fixed roof tank having the membrane attached to its cylinder and to a smaller diameter inner roof. Note that *API 620* states that it does not apply to lift-type gas holders; refer to *API 575* for additional information on this type of tank.

The breather roof type of tank is intended to permit some small volume change to accommodate vapor accumulation for internal breathing (pressure approximately limited to the weight of the roof panels) for storage of volatile liquids. A supported, flexible metallic roof of flat or slightly concave contour can rise off its structural framing and act as a self-supporting roof as the vapor space pressure increases. No general industrial design standard exists for this type of roof. *API 575* illustrates the salient features of such a tank.

The balloon roof type of tank offers higher vapor volume changes than do the breather roof types. The flexible roof is externally stiffened and counterweighted and can withstand greater vapor space pressure than can the breather roof types. Balloon roof tanks are anchored. Typical internal design pressures do not exceed 1 to

2 ounces per square inch gage. No general industrial design standard exists for the balloon roof type of tank. *API 575* illustrates such tanks.

4.4.1.4 Structurally Supported Aluminum Dome Roofs

Structurally supported aluminum dome roofs are described in Appendix G of *API 650*. The roof is an all-aluminum, clear-span, self-supporting space truss with aluminum panels. An integral tension ring takes the primary horizontal thrust. The roof is attached to and supported by the tank at mounting points equally spaced around the perimeter of the top shell. These roofs are available in diameters exceeding 300 feet.

Structurally supported aluminum domes are used in the following configurations:

- To convert external floating roof tanks to covered floaters
- Over new internal floating roofs
- For replacement of existing deteriorated steel roofs

4.4.1.5 Vapor Conservation Tanks

Vapor conservation tanks are sometimes referred to as “variable-vapor space tanks.” To accommodate the evaporation loss inherent with a cone roof tank, where the expanding air-vapor mix must be vented, a vapor conservation device is often used. The device provides a dry air or gas blanket on an existing fixed roof tank (some alteration to the tank, such as a heavier top angle, may be required).

Types of vapor conservation tanks include the following:

- Gas holder (wet seal/dry seal types, single/multiple lift, etc.)
- Flexible membrane

Note: It may be possible to tie other gas-tight cone roof tanks with a vapor storage unit through interconnected piping, forming a vapor-saving system.

Membrane or similar type of fabric material is subject to pinhole leaks or tears. Unlike the fabric in a floating roof seal, this material may be difficult to inspect and repair.

4.4.1.6 Vapor Bladder Tanks

Vapor bladder tanks have also been built. With the advent of vapor recovery in petroleum distribution systems, vapor domes were retroactively added to existing cone roof tanks to add greater vapor space. These were typically small dome cupolas lined with flexible rubber bladders of slightly smaller size than the external roof. Later full-diameter hemispherical and structurally supported dome roofs were built with suspended rubber bladders of greater volume than the earlier vapor domes.

The vapor bladder-type tank having the ring-type truncated cone offers even greater volume capacity change with its more uniform liner shape transition, attributable to its tensioned shroud lines from the bladder to a central internal counterweight. No general industrial design standard exists for vapor bladder tanks. Refer to Myers (1997) and *API 575*, which generally describe such tanks.

In general, if these tanks are for atmospheric pressure applications, then *API 650* is applied in their design. If internal pressure is a design load, then *API 620* is applied. For spherical shapes or for other non-cylindrical shapes, *API 620* is used, regardless of the pressure. These standards do not cover all details, however.

4.4.2 Low-Pressure Tanks

API 620 defines design and construction of large, welded, field-erected storage tanks operated at a gas pressure of 15 psig and less, with a configuration of a single vertical axis of revolution. Depending on design pressure and capacity, low-pressure storage tanks may be any of the following:

- Cylindrical with flat bottom and dished or coned roof
- Cylindrical with both roof and bottom dished or coned
- Spherical
- Spheroidal

Anchored flat bottom tanks are defined by *API 620*, as well.

Appendix R of *API 620* provides rules for refrigerated products with storage temperatures from +40ºF to -60ºF. Typical products stored in Appendix R-type tanks include butane and propane. These products are stored at temperatures near their boiling points. For example, commercial propane is stored at -45.6ºF.

Appendix Q has rules for storage temperatures from -60ºF to -270ºF and includes stainless steel, nickel alloy, and aluminum materials. Stored products, such as ethylene at -154ºF and methane at -259ºF, fall in the Appendix Q category.

4.4.3 Other Storage

4.4.3.1 Vessels are also an option for storage at pressures below 15 psig even though the vessel code, *ASME Code, Section VIII, Division 1*, covers design pressures above 15 psig. When the vessel is “bullet-shaped,” having a horizontal axis of revolution, with formed heads, *ASME Code, Section VIII, Division 1*, provides rules for design that are more applicable than those of *API 620*. Refer to *PIP VESLP001* for requirements for low-pressure vessels.

4.4.3.2 Fiberglass tank requirements are covered by the following:

ASME Section X covers the minimum requirements for the fabrication of fiber-reinforced thermosetting plastic pressure vessels for general service. Class I vessels shall not exceed 150 psi (1000 kPa) for bag-molded, centrifugally cast, and contact-molded vessels; 1500 psi (10,000 kPa) for filament-wound vessels; and 3000 psi (20,685 kPa) for filament-wound vessels with polar boss openings. Class II vessels are limited to diameter and pressure controls, such as 144 inches in diameter and 200 psig. Additional restrictions apply, however, that may decrease these limits.

API 12P describes material, design, fabrication, and testing requirements for fiberglass-reinforced plastic (FRP) tanks. Only shop-fabricated, vertical, cylindrical tanks are covered. Tanks covered by *API 12P* are intended for aboveground and atmospheric pressure service. Unsupported cone bottom tanks are outside the scope of *API 12P*.

ASME RTP-1 covers the materials of construction, design, fabrication, quality control, and inspection of reinforced thermoset plastic (RTP) vessels that operate at pressures not exceeding 15 psig externally and/or 15 psig internally above any hydrostatic head and vessels that contain corrosive and otherwise hazardous materials.

ASTM D3299-00 covers cylindrical tanks fabricated by filament winding for aboveground vertical installation to contain aggressive chemicals at atmospheric pressure (± 0.5 psig), as classified therein, and made of a commercial-grade polyester or vinyl ester resin. Included are requirements for materials, properties, design, construction, dimensions, tolerances, workmanship, and appearance.

ASTM D4097 covers cylindrical tanks fabricated by contact molding for aboveground vertical installation, to contain aggressive chemicals at essentially atmospheric pressure (± 0.5 psig), and made of a commercial-grade polyester or vinyl ester resin. Included are requirements for materials, properties, design, construction, dimensions, tolerances, workmanship, and appearance.

PIP VESFG001 covers the general materials selection, design, fabrication, testing, inspection, and documentation requirements for fiberglass vessels and tanks to be constructed in accordance with *ASME Boiler and Pressure Vessel Code, Section X,* or *ASME/ANSI RTP-1*.

4.4.3.3 Vessels designed according to *ASME Section VII, Division 1,* are a good alternative for storage where deflagration or detonation design considerations must be incorporated.

4.4.3.4 *NACE RP0294* covers design, fabrication, and inspection of tanks in concentrated sulfuric acid and oleum service.

4.4.4 Advantages and Disadvantages of the Various Tank Types

Some of the advantages and disadvantages to consider when selecting a tank type are as follows:

A. Fixed roof tanks:

1. Fixed roof tanks have breathing and filling losses.
2. Fixed roof tanks may have vapor space corrosion.
3. Maintenance is simpler for fixed roof tanks.
4. Fixed roof tanks are generally more economical than are other types for smaller diameters, generally less than 50 feet.
5. Some fixed roof types can be seal welded if internal lining is required.

B. Self-supporting roofs:

1. Access can be difficult (because of roof slope).
2. When a frangible joint is not possible, special venting provisions may be required.
3. No internal supports interfere with underside access.
4. Seal welding is possible (any framing necessary can be placed on exterior).
5. Cost is more than that for a supported roof.

C. Floating roof tanks:

1. This is the most effective conservation tank for non-pressure storage.
2. Fire hazard is low because of the absence of a vapor zone.
3. External floaters may be competitive with cone roofs in large sizes when consequent values of vapor losses are considered.
4. Exposed, unprotected shell plates can contaminate stored product by corrosion.
5. External floaters may pose drainage problems.
6. External floaters are difficult to operate in cold climates.
7. From a maintenance standpoint, the internal floating roof tank provides the benefits of floating roof emission control at the low cost of a fixed roof tank.
8. Corrosion of carbon steel floating roofs must be monitored to ensure structural integrity.

D. Lifter roofs:

1. Lifter roofs are the least expensive roof for high-purity, low turnover-frequency storage.
2. Lifter roofs can serve as variable vapor space reservoirs if connected to other tanks via tank vapor space connections.
3. Industry standards for this type of tank do not exist.

E. Breather roofs (membrane bag or guided piston in vapor zone):

1. Breather roofs offer greater vapor capacity than do lifter roofs. They also reduce filling losses (to nil when diaphragm is same diameter as tank).
2. Product is fully protected from contamination or vapor dilution.
3. Filling losses are less than for fixed roofs but are not completely eliminated.
4. Maintenance on seal is required.
5. Maintenance is required on membrane or piston.
6. Industry standards for this type of tank do not exist.

F. Structurally supported aluminum dome roofs:

1. Product emissions can be reduced because domes eliminate the wind evaporative effect and lower product temperature by reflecting sunlight.
2. A dome will keep water out and therefore off the floating roof, thereby lowering risk of problems with disposal of water and contamination of sensitive products. In areas of snow and ice accumulation, roof drain problems are reduced. This feature may be attractive for tank terminals that are remote and that may not have water treatment facilities, such as a marketing terminal.
3. Aluminum construction resists corrosion, thereby reducing maintenance costs.
4. Some details are not covered by industry standards.
5. Some components used on external floating roofs can be eliminated.

4.5 Selection of Tank Size

Factors that may affect the size or dimensions of tank(s) to be chosen for a particular service include the following:

- Land costs
- Soil conditions
- Regulations for diking and tank spacing
- Shipping limits
- Site conditions
- Type of tank roof used

5. Selection of Tank Components

This section provides guidance on the issues associated with the selection of tank components, such as the shell, roof, bottom, and foundation.

5.1 General

5.1.1 Tankage should be in accordance with applicable jurisdiction's rules and regulations, such as those of EPA and OSHA, or equivalent local, regional, or national regulations.

5.1.2 Tank Data Sheets should be used to specify such information as the following:

- Tank geometry or capacity
- Metallurgy of components and corrosion allowance
- Design loads and load combinations
- Applicable code or allowable stresses
- Other significant information, such as the climatic design data, which is needed by the tank manufacturer to determine plate thicknesses and sizing of other tank components

Note: PIP VEDTA003 illustrates the complete data required to specify an *API 650* tank.

5.2 Foundations

5.2.1 In most cases, the foundation and its design are furnished by Purchaser (or someone other than the Manufacturer of the tank).

5.2.2 The party responsible for furnishing the foundation should prepare or obtain a soil report indicating the allowable soil-bearing pressure. The subsurface investigation and resulting bearing value should come from a qualified soils engineer.

5.2.3 Soil-bearing pressure is the primary factor in selecting the proper type of foundation. Generally, the most economical storage cost results from using the tallest tank that the soil will support without excessive settlement. If a low-soil-bearing pressure indicates using less economical tank proportions, alternate foundation schemes should be explored.

5.2.4 Foundations for tanks storing heated or cold products present special problems. Experienced and qualified expertise is required to assure that adequate design is performed. For proper and economical design of foundations, every site should have a subsoil investigation. Random exploration is not recommended. Generally the norm for large tanks is a minimum of three borings, equally spaced at 120 degrees on a circumscribing circle 5 feet outside the foundation. The soils engineer shall specify allowable soil-bearing pressure on the basis of given tank loads and results of the investigation.

5.2.5 Foundations for flat bottom tanks generally fall into the following broad categories:

- Earth foundations (without a concrete ringwall)
- Concrete ringwall (with or without a concrete footing)
- Concrete slab, floating or pile-supported

5.2.6 In many cases, foundations for flat bottom tanks can be earthen types without a concrete ringwall. For larger tanks, particularly floating roof tanks, a concrete ringwall foundation has definite advantages. Uneven settling of the foundation can cause the tank to go out of round, causing the seal to lose its effectiveness or, in some cases, causing the roof to jam.

5.2.7 Good foundation design, regardless of type, should provide for suitable drainage, which helps keep the bottom dry.

5.3 Bottom

5.3.1 Unless specified otherwise, tank bottom plates for flat bottom tanks should be lap welded. For tanks installed on grillage, butt-welded bottom plates should be used.

5.3.2 Lap-welded bottom plates should provide a shingle such that the product drains in a downward direction, with no pockets at overlap weld seam to trap product.

5.3.3 A crowned bottom (coned up at tank center), if specified, may facilitate cleaning and compensate for the somewhat extra settlement that occurs at the tank center relative to the outer edge.

5.3.4 The Tank Data Sheet should state the type of bottom configuration, including slope requirement, and state whether undertank leak detection and subgrade protection is required. Bottom slope for crown or cone bottom tanks may vary depending on the tank's intended service.

5.3.5 Of all major tank components, the bottom is probably the most often repaired or replaced. *API 653* provides a long list of causes of bottom failures that necessitate appropriate corrective action.

5.4 Shell

5.4.1 The shell plate thicknesses are typically determined by the Manufacturer, using design loads, design criteria, tank geometry, and material allowable stresses, as specified by the Purchaser on the Tank Data Sheet.

5.4.2 Optional design procedures, offered by *API 650* for example, permit higher design stresses in return for a more refined engineering design, greater inspection, and use of shell plate steels with demonstrably improved toughness. Tanks built with a refined design procedure will have thinner shells and therefore reduced resistance to buckling under wind when empty or when subject to external pressure or vacuum.

5.4.3 If additional shell stiffness is required, the tank designer may use either increased shell plate thickness or intermediate windgirders.

5.4.4 Anchorage of a tank to a concrete foundation may be necessary because of internal pressure, wind, seismic loading, prevention of flotation, or possibility of deflagration.

5.4.5 Windgirders used for personnel access may require handrailing past the stairway opening.

5.5 Roof

5.5.1 General

5.5.1.1 Minimum slope of an *API 650* column-supported cone roof is 3/4 inch per foot. Increasing this slope should be done with caution. A relatively flat roof will follow the variations resulting from differential settlement. A steeper cone roof may develop buckles.

5.5.1.2 Appendix F of *API 650* provides details of roof-to-shell junction for tanks where an internal pressure has been specified. Otherwise, a frangible joint is desired where one is possible. The purpose of the frangible joint roof seam is to provide a “weak” joint that will fail under excessive internal pressure before failure occurs in the tank shell joints or the shell-to-bottom connection.

5.5.1.3 Roofs that are to be internally coated should be seal welded on inside and outside or should be double butt-welded.

5.5.1.4 If the service requires an internal lining or coating, consideration should be given to selecting a roof that does not require internal support. This will minimize surface area and present a smooth interior for coating and future maintenance. If the frangible feature is lost, emergency-venting devices should be provided.

5.5.1.5 Tanks with self-supporting cone, dome, and umbrella roofs are cost competitive with column-supported cone roof tanks in diameters smaller than approximately 50 feet. It may be necessary, however, to specify self-supporting roofs because of the intended tank service (coating or lining requirements, internal pressure, etc.).

5.5.1.6 Self-supporting cone roofs do not require framing. This puts a limit on their diameter. *API 650* limits roof slope to a minimum of 2:12 and a maximum of 9:12. Thickness range is from 3/16 inch (minimum) to 1/2 inch (maximum). A tank Manufacturer would probably butt weld roof plates at thicknesses greater than 3/8 inch. The steeper roof slope affects the capability to support personnel on the roof and therefore adds to the cost of walkways and platforms.

5.5.2 Dome and Umbrella Roofs

5.5.2.1 Dome Roof

5.5.2.1.1 A dome roof is formed to the surface of a spherical segment.

5.5.2.1.2 Dome plates are dished and supported only at the periphery. Framing is generally required only for construction purposes and can be removed after erection.

5.5.2.2 Umbrella Roof

5.5.2.2.1 An umbrella roof consists of wedge-shaped sections formed in one direction (not dished).

5.5.2.2.2 Permanent framing may be required on umbrella roofs.

5.5.2.3 Framing

If service conditions dictate that the tank be internally lined or coated, it may be best to specify that any framing required be placed on the exterior. If external framing is required, consideration should be given to seal welding the members to avoid crevice corrosion, rust streaks, and paint discoloration. External framing is a potential tripping hazard.

5.5.3 External Floating Roof

5.5.3.1 External floating roofs (in open top tanks) are designed to float directly on the product.

5.5.3.2 The types of external roofs are pan, pontoon, and double deck.

5.5.3.3 The pan-type floating roof is a poor design for external floaters because of its instability and tendency to sink. Pan-type roofs are generally unstable for open top floating roof tank applications and should not be used. Pan-type floating roofs are not popular because of their instability under wind, water, and snow loads and with vaporizing liquids.

Note: *PIP VESTA002* prohibits the use of pan roofs.

5.5.3.4 Single deck roofs, also called pontoon floating roofs, consist of a deck supported by annular pontoons. Many variations exist but the majority are designed to float directly on the product. The single center deck of a pontoon floating roof can be designed to balloon upward when the stored product boils, thus retarding further vapor formation. The deck slopes downward under water load and permits withdrawal through the drains.

5.5.3.5 Single deck pontoon roofs with compartmental annular pontoons have good load-carrying capacity and flotation stability.

5.5.3.6 In locations with unusual wind conditions or on very large diameter tanks, the center deck of the pontoon roof may have a tendency to flex considerably, causing fatigue cracks in welds. Stiffeners or seal welding from both sides may be required to reduce flexing.

5.5.3.7 The single deck annular pontoon-type deck is somewhat susceptible to vapor loss on products having high vapor pressures.

5.5.3.8 Of the several external floating types available, the single deck annular pontoon design is preferred because of initial cost. In sizes smaller than approximately 40 feet in diameter, double deck pontoons are typically more cost effective than are the annular pontoon type.

5.5.3.9 Double deck floating roofs have two complete decks over the liquid surface. Double deck floating roofs provide good insulation (which retards boiling of product), simplified drainage, a clear and maintenance-free deck, good stability in areas of constant steady winds, and good performance in high-rainfall areas. The cost of double deck roofs may be more than other types.

5.5.4 Internal Floating Roof

5.5.4.1 The common types of internal roofs are as follows:

- Metallic (usually aluminum or stainless steel) roofs on floats
- Pontoon or double deck metallic roofs
- Other internal roofs using metallic or plastic sandwich panels
- Composite glass-reinforced panels with self-buoyant cores

5.5.4.2 Either the desired net working capacity or the tank dimensions should be clearly indicated on the Tank Data Sheet for the Manufacturer to properly design the tank. Each Manufacturer has slightly different freeboard measurements, resulting from seal device configurations, the fixed roof framing arrangement, and provisions for foam makers/foam dams and secondary seals.

5.5.4.3 Internal floating roofs may not be appropriate for the following:

- Butane-blending procedures
- Hydrocarbons with high vapor pressures
- Gaseous products
- Mixing operations

5.5.4.4 Any one or a combination of the above-listed conditions or substances could cause severe agitation of the product under the roof, resulting in splashing of liquid onto the roof around the seals and possible sinking of the roof. The service conditions should be clearly specified on the Tank Data Sheet.

5.5.4.5 Existing cone roof (or preferably self-supporting roof) tanks can be altered to covered floaters with the addition of an internal roof. The following should be considered before installing an internal floating roof in an existing tank:

- Condition of tank - Consider whether it is out of round, has severe buckles, has a riveted shell, is out of level, has internal shell attachments, etc.

- Internal framing - Consider the type of columns (column seals). Some older tanks may have internal bracing that must be removed.
- Manway size and location - An additional manway(s) and platform(s) may need to be installed to provide installation and maintenance access for the internal floating roof.
- Roof inlet nozzles - These nozzles should be modified to provide an extension.

5.5.4.6 The need for operating space for internal roof accessories (secondary seal, foam chambers, foam dam) may reduce capacity.

5.5.5 Structurally Supported Aluminum Dome Roof

In many cases, the structurally supported aluminum dome roof is used in a retrofit situation, e.g., when converting an existing open top floating roof tank to a covered floater. Usually the upper shell of the existing tank requires some reinforcement to accommodate the point loads imposed by the dome roof.

6. Selection of Tank Accessories

This section provides guidance on the more common tank accessories. Not all tanks have all these accessories.

6.1 Floating Roof Seals

6.1.1 The seal or sealing system is designed to close the annular rim-shell space. Properly designed systems will function as follows:

- Accommodate the gap between the floating roof and the shell
- Allow normal roof movement
- Provide protection from weather (wind, rain, lightning) and fire

6.1.2 Seal systems should be designed in accordance with existing jurisdictional regulations.

6.1.3 Evaporative loss from floating roof seals can be reduced by the following techniques:

- Installing a primary seal with a low rim seal loss factor
- Reducing gaps in the primary seal
- Reducing gaps in the secondary seal

6.1.4 Because they lack the large rim vapor space below the primary seal, liquid-mounted primary seals have lower losses than do vapor-mounted primary seals.

6.1.5 Rim-mounted secondary seals effectively reduce rim seal losses by decreasing the wind-related convection effect on the evaporative loss from the primary seal. Secondary seals also reduce the potential for lightning fires.

6.1.6 Seals generally fall into two broad categories: metallic and non-metallic. The most common types are mechanical shoe seals and resilient toroidal envelope seals (liquid-filled or foam logs).

6.1.7 Primary seals are always required on floating roofs. Secondary seals may also be required for special service conditions or by air pollution regulations.

6.1.8 Most Manufacturers have their own supply of primary and secondary seals. Several other Manufacturers offer a wide spectrum of seal configurations.

6.2 Nozzles and Manways

6.2.1 Normally, most pipe connections through the shell are located in the first shell course.

6.2.2 Generally, the Manufacturer assumes that any piping load will be evaluated by the piping designer. However, Appendix P of *API 650* contains information regarding first-course shell connections subjected to external pipe loading.

6.2.3 Nozzles and manways should not be located in weld seams. By agreement between Purchaser and Manufacturer, API permits covering weld seams with added configuration and examination requirements. On existing tanks, *API 653* provides rules for minimum weld spacing at shell penetrations.

6.2.4 *AWWA D-100* requires two manways in the first ring of the tank. *API 650* requires the Purchaser to determine the size and number of shell and roof manways according to needs.

6.3 Vents

6.3.1 *API 2000* sets forth venting requirements for nonrefrigerated aboveground tanks in Section 1 and refrigerated aboveground and underground tanks in Section 2.

6.3.2 Additional venting capacity on fixed roof hot-oil tanks or tanks of similar service should be considered.

6.4 Mixers

6.4.1 Fixed angle mixers are satisfactory for blending operations.

6.4.2 For sediment and water control, variable-angle mixers should be considered, or the quantity of fixed angle mixers should be increased. Each mixer should have a dedicated manway or nozzle connection.

6.4.3 Other kinds of mixing devices, such as vertical roof agitators or eductors, are also used.

6.5 Drains

6.5.1 Two types of primary drainage systems are used to remove water from the top of an external floating roof:

1. Closed system, using pipe or hose where water does not come in contact with stored product

   Note: Pontoon-type floating roofs typically have a check valve at the upper end to prevent product from flowing onto the deck in case of a leak in the drain piping. Double deck roofs do not require a check valve. Drain outlet shall have a gate valve, which is usually kept closed, except when draining the roof, to prevent loss of product in the event of drain failure.

2. Open drain, where water flows down through the product

6.5.2 Emergency drains, which drain directly into the product, are needed on double deck floating roofs to prevent excessive water accumulation.

6.6 Swinglines

6.6.1 Swinglines (also called "floating suction lines") facilitate filling or withdrawing product from a designated or variable level other than near the bottom of tanks.

6.6.2 The two general types of swinglines are as follows:

1. Floating swingline, which places the end of an articulated pipe near the product surface

   This type can be used on floating or fixed roof tanks.

2. Simple swingline, consisting of single internal pipe and a swing joint, for which a winch is used to adjust the position

6.7 Platforms, Walkways, and Stairways

6.7.1 The type of stairway (helical or straight along a radius) should be indicated on the Tank Data Sheet.

6.7.2 If roof slope on a cone roof tank exceeds 1:12 or if snow or ice conditions are expected, platforms should be considered at all roof connections.

6.7.3 Access between tanks, if appropriate, may be via a crosswalk. The crosswalk and connections should be designed to accommodate any differential movement between tanks.

7. Protection and Verification

7.1 Fire and Lightning Protection

7.1.1 General

7.1.1.1 Fire protection is defined in *NFPA 11*, *NFPA 15*, and *NFPA 30*.

7.1.1.2 Lightning protection is defined in *API 2003* and *NFPA 780*.

7.1.1.3 Fireproofing of supports, such as legs on a sphere, is defined in *ASTM C-33* and *ASTM C-150*.

7.1.2 Foam Systems

7.1.2.1 Cone or Fixed Roof Tanks

Foam protection should be considered for the liquid surface. Refer to *NFPA 11* for more information on foam systems. Generally accepted methods are as follows:

- Shell-mounted foam chambers
- Portable tower/monitor
- Subsurface (base injection)

7.1.2.2 Floating Roof Tanks

7.1.2.2.1 Foam protection systems are usually designed to extinguish fires in the seal area. Typical methods are the following:

- Shell-mounted foam chambers
- Catenary system using fixed piping on the floating roof with foam discharge outlets into the seal area
- System using rigid and flexible piping inside the tank and mounted on the roof with foam discharge piping directed to the seal area

7.1.2.2.2 External floating roofs require that foam dams be attached to the top deck. A foam dam traps foam around the periphery of the roof to extinguish a rim fire.

7.1.2.2.3 Depending on roof type, the foam dam is generally attached to the top of the outer rim of internal floating roofs. Upper travel of roof is slightly reduced on internal roofs with foam dams.

7.1.3 Deluge Systems

7.1.3.1 Use of water deluge for tanks may be dictated by any of the following:

- Fire protection
- Safety rules
- Other jurisdiction

7.1.3.2 Tanks are typically protected by a water deluge system consisting of spray nozzles or a circular weir that allows a uniform film of water to flow over the tank surface.

7.1.3.3 Deluge systems have caused corrosion problems under insulation.

7.2 Painting and Internal Coating (Lining)

7.2.1 Corrosion of internal tank surfaces may occur after the hydrotest and before the tank is placed in service. The use of a rust preventative should be evaluated.

7.2.2 Tanks in the following services are commonly internally coated:

- Condensate
- Demineralized water
- Neutralization
- Caustic
- Potable water
- Clarified water
- Wastewater

7.2.3 Lining of aboveground storage tank bottoms is defined in *API 652* and *NACE RP0178*.

7.2.4 Surface conditions affect paint performance and future maintenance. Accordingly, seal welding and even grinding may be required, especially on interior surfaces.

7.2.5 Seal welding is especially important in areas that are difficult to inspect and maintain, such as interior attachments and the underside of external windgirders and stiffeners.

7.2.6 Grinding welds so that they are smooth, and especially flush, is an expensive process. The cost is a function of the degree of weld preparation required for a particular lining or coating system. Use of grinding samples is an effective way to convey the desired end product.

7.2.7 Fiberglass or other composite linings of the tank bottom and lower shell should be specified on the basis of the corrosion conditions expected and the required tank life. Thick film linings are commonly used in crude oil storage tanks. Other proprietary systems are also available.

7.3 Cathodic Protection

Cathodic protection is also a means to be considered to resist tank corrosion.

7.4 Testing

7.3.1 Testing that involves the bottom, shell, and roof should be considered for every new tank.

7.3.2 *API 650* Appendixes C, H, and G address floatation and leak tests for external and internal floating roofs and structurally supported aluminum dome roofs, respectively.

7.3.3 *API 653* provides rules for testing tanks that have been repaired, altered, or reconstructed.

7.3.4 Consideration should be given to the temperature and quality of test water. Supply and disposal of test water are generally the responsibility of the Purchaser.

7.3.5 Potential danger of corrosion from test water should be addressed. Special procedures should apply, as appropriate, considering the material of construction of the tank or tank components and the quality of the test water. Refer *to PIP VESTA002* for a list of issues related to test water.