

## SECTION 6

# Storage

This section provides general guidelines that will aid in the selection of the proper type of storage to be used in a particular application. Fig. 6-2 will assist with the selection. Various codes, standards, and recommended practices should be used

to supplement the material provided. Manufacturers should be consulted for specific design information pertaining to a particular type of storage.

**FIG. 6-1**  
**Nomenclature**

$A', B', C', D'$  = coefficients used in Fig. 6-14

$A$  = surface area,  $m^2$

$b$  = ellipse minor radius,  $m$

$B_{max}$  = vapor pressure of liquid at maximum surface temperature,  $kPa$  (abs)

$B_{min}$  = vapor pressure of liquid at minimum surface temperature,  $kPa$  (abs)

$D$  = cylinder diameter,  $m$

$f(Z_c)$  = cylinder partial volume factor, dimensionless

$f(Z_e)$  = head partial volume factor, dimensionless

$H$  = correction factor for horizontal surfaces

$H_n$  = depth of liquid in cylinder,  $m$

$H_p$  = height of liquid,  $m$

$H_T$  = height,  $m$

$k$  = thermal conductivity,  $W/(m \cdot K)$

$K$  = equilibrium constant,  $y/x$ , dimensionless

$K_l$  = head coefficient, dimensionless

$L$  = length,  $m$

$MW_i$  = molecular mass of component  $i$

$n_g$  = number of moles of vapor

$n_i$  = number of moles of component  $i$

$P$  = absolute pressure,  $kPa$  (abs)

$P_a$  = atmospheric pressure,  $kPa$  (abs)

$P_c$  = critical pressure,  $kPa$  (abs)

$P_R$  = reduced pressure, dimensionless

$Q$  = heat flow,  $W/m^2$

$R$  = gas constant,  $8.31 kPa \cdot m^3/K \cdot kmole$

$R_l$  = cylinder radius,  $m$

$R_i$  = thermal resistance of insulation ( $X/k$ ),  $K \cdot m^2/W$

$T$  = temperature,  $K$

$T_a$  = ambient air temperature,  $^{\circ}C$

$T_c$  = critical temperature,  $K$  or  $^{\circ}C$

$T_f$  = temperature drop through surface air film,  $^{\circ}C$

$T_h$  = hot face temperature,  $^{\circ}C$

$T_i$  = temperature drop through insulation,  $^{\circ}C$

$T_m$  = mean temperature of insulation,  $^{\circ}C$

$T_{max}$  = maximum average temperature,  $^{\circ}C$

$T_{min}$  = minimum average temperature,  $^{\circ}C$

$T_R$  = reduced temperature, dimensionless

$T_s$  = outside surface temperature,  $^{\circ}C$

$V$  = volume,  $m^3$

$W$  = width,  $m$

$x_i$  = mole fraction of component  $i$  in the liquid phase

$X$  = insulation thickness,  $mm$

$y_i$  = mole fraction of component  $i$  in the vapor phase

$Z$  = compressibility factor

### Greek

$\alpha$  = radians

$\Delta$  = absolute internal tank pressure at which vacuum vent opens,  $kPa$  (abs)

$\pi$  = 3.14159...

$\phi$  = required storage pressure,  $kPa$  (abs)

$\Sigma$  = summation

**DP** = design pressure is the pressure at which the most severe condition of coincident pressure and temperature expected during normal operation is reached. For this condition, the maximum difference in pressure between the inside and outside of a vessel or between any two chambers of a combination unit shall be considered. (ASME Code for Unfired Pressure Vessels, Section VIII)

**MAWP** = maximum allowable working pressure shall be defined as the maximum positive gauge pressure permissible at the top of a tank when in operation, which is the basis for the pressure setting of the safety-relieving devices on the tank. It is synonymous with the nominal pressure rating for the tank as referred to in API Standards 620 and 650.

**OP** = operating pressure is the pressure at which a vessel normally operates. It shall not exceed the maximum allowable working pressure of the vessel. A suitable margin should be allowed between the pressure normally existing in the gas or vapor space and the pressure at which the relief valves are set, so as to allow for the increases in pressure caused by variations in the temperature or gravity of the liquid contents of the tank and other factors affecting the pressure in the gas or vapor space. (API Standard 620)

**RVP** = Reid Vapor Pressure is a vapor pressure for liquid products as determined by ASTM test procedure D-323. The Reid vapor pressure is defined as pounds per sq in. at  $37.8^{\circ}C$ . The RVP is always less than the true vapor pressure at  $37.8^{\circ}C$ .

**TVP** = true vapor pressure is the pressure at which the gas and liquid in a closed container are in equilibrium at a given temperature.

**FIG. 6-2**  
**Storage**

|                     | Atmospheric Pressure†‡ | 0 to *17 kPa (ga)†‡ | 17 to 100 kPa (ga)‡ | Above 100 kPa (ga)§ | Underground |
|---------------------|------------------------|---------------------|---------------------|---------------------|-------------|
| Crude Oils          | X                      | X                   | X                   | —                   | X           |
| Condensate          | X                      | X                   | X                   | X                   | X           |
| Oils                | X                      | X                   | —                   | —                   | X           |
| Natural Gasoline    | X                      | X                   | X                   | —                   | X           |
| Butanes             | —                      | X°                  | X°                  | X                   | X           |
| Propane             | —                      | X°                  | X°                  | X                   | X           |
| Raw NGLs            | —                      | X°                  | X°                  | X                   | X           |
| Ethane              | —                      | X°                  | X°                  | X                   | X           |
| Petrochemicals      | —                      | X°                  | X°                  | X                   | X           |
| Natural Gas         | —                      | —                   | —                   | X                   | X           |
| LNG                 | —                      | X°                  | X°                  | X                   | —           |
| Treating Agents     | X                      | X                   | —                   | —                   | —           |
| Dehydration Fluids  | X                      | X                   | —                   | —                   | —           |
| Specialty Chemicals | X                      | X                   | X                   | —                   | —           |
| Solid Materials     | X                      | —                   | —                   | —                   | —           |
| Water               | X                      | —                   | —                   | —                   | —           |

\* Some materials may require a slight positive pressure to exclude air, oxygen, and/or water, and conserve valuable/toxic vapors.  
 † API Standard 650 governs  
 ‡ API Standard 620 governs  
 § ASME Unfired Pressure Vessel Code, Section VIII governs  
 ° Refrigerated only  
 Note: Vacuum conditions may exist and must be considered in tank design.  
 Examples: low ambient temperatures or evacuating without relieving.

## STORAGE CLASSIFICATION

### Above Ground

**Atmospheric** — Atmospheric pressure tanks are designed and equipped for storage of contents at atmospheric pressure. This category usually employs tanks of vertical cylindrical configuration that range in size from small shop welded to large field erected tanks. Bolted tanks, and occasionally rectangular welded tanks, are also used for atmospheric storage service.

**Low Pressure [0 to 17 kPa (ga)]** — Low pressure tanks are normally used in applications for storage of intermediates and products that require an internal gas pressure from close to atmospheric up to a gas pressure of 17 kPa (ga). The shape is generally cylindrical with flat or dished bottoms and sloped or domed roofs. Low pressure storage tanks are usually of welded design. However, bolted tanks are often used for operating pressures near atmospheric. Many refrigerated storage tanks operate at approximately 3.5 kPa (ga).

**Medium Pressure [17 to 100 kPa (ga)]** — Medium pressure tanks are normally used for the storage of higher volatility intermediates and products that cannot be stored in low pressure tanks. The shape may be cylindrical with flat or dished bottoms and sloped or domed roofs. Medium pressure tanks are usually of welded design. Welded spheres may also be used, particularly for pressures at or near 100 kPa (ga).

**High Pressure [Above 100 kPa (ga)]** — High pressure tanks are generally used for storage of refined products or fractionated components at pressure above 100 kPa (ga). Tanks are of welded design and may be of cylindrical or spherical configuration.

### Underground

Gas processing industry liquids may be stored in underground, conventionally mined or solution mined caverns. No known standard procedures are available for this type storage; however, there are many publications and books covering the subject in detail.

## WORKING PRESSURES

A design working pressure can be determined to prevent breathing, and thereby save standing storage losses. However, this should not be used in lieu of any environmental regulatory requirements regarding the design of storage tanks. The environmental regulatory requirements for the specific location should be consulted prior to the design of storage facilities. Generally there are regulatory requirements specifying the type of storage tank to be used, based on the storage tank capacity and the vapor pressure of the product being stored. In addition there are usually specific design requirements, for example in the type of seals to be used in a floating roof tank.

The working pressure required to prevent breathing losses depends upon the vapor pressure of the product, the temperature variations of the liquid surface and the vapor space, and the setting of the vacuum vent.

$$\phi = B_{\max} + (\Delta - B_{\min}) \frac{(T_{\max} + 273)}{(T_{\min} + 273)} - P_a \quad \text{Eq 6-1}$$

The above relation holds only when  $B_{\min}$  is less than  $\Delta$ ; that is, when the minimum vapor pressure is so low that air is admitted into the vapor space through the vacuum vent. When  $B_{\min}$  is equal to or greater than  $\Delta$ , the required storage pressure is,

$$\phi = B_{\max} - P_a \quad \text{Eq 6-2}$$

Under this condition air is kept out of the vapor space.

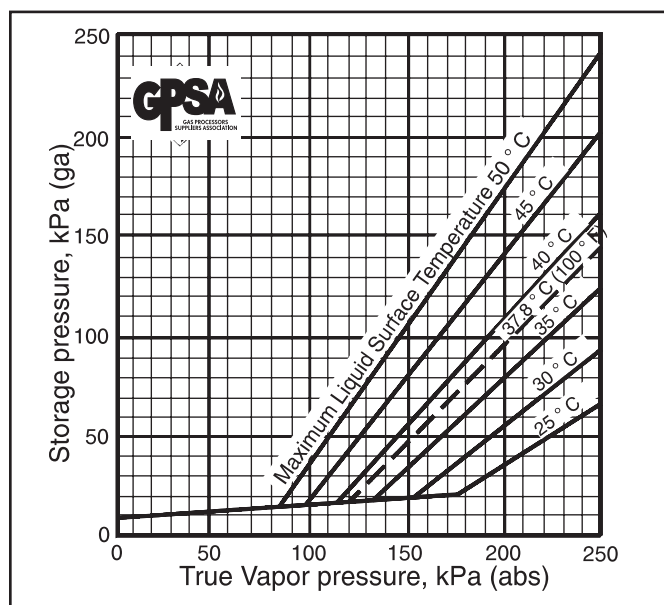
Fig. 6-3 is presented as a general guide to storage pressures for gasolines of various volatilities in uninsulated tanks. These data for plotting the curves were computed from Eqs 6-1 and 6-2 using the following assumptions:

- Minimum liquid surface temperature is 5°C less than the maximum liquid surface temperature.
- Maximum vapor space temperature is 22°C greater than the maximum liquid surface temperature.
- Minimum vapor space temperature is 8°C less than the maximum liquid surface temperature.
- Stable ambient conditions (ambient temp. 38°C).

These temperature variations are far greater than would be experienced from normal night to day changes. Therefore, the lower, nearly horizontal line, which shows a required storage pressure of 17 kPa (ga) for the less volatile gasolines is conservative and allows a wide operating margin.

FIG. 6-3

#### Storage Pressure vs. True Vapor Pressure



Maximum liquid surface temperatures vary from 29 to 46°C. Sufficient accuracy will generally result from the assumption that it is 5°C higher than the maximum temperature of the body of the liquid in a tank at that location.

**Example 6-1** — To illustrate the use of Fig. 6-3, suppose a 165 kPa (abs) true vapor pressure (TVP) natural gasoline is to be stored where the liquid surface temperature may reach a maximum of 38°C. A vertical line extended upward from the 165 kPa (abs) mark at the bottom of the chart intersects the 38°C line at 64 kPa (ga). The design pressure of the tank should be a minimum of 70.5 kPa (ga) (64 kPa + 10%).

Fig. 6-4 can be used as follows:

- As quick reference to determine true vapor pressures of typical LPGs, natural gasolines, and motor fuel components at various temperatures.
- To estimate the operating pressure of a storage tank necessary to maintain the stored fluid in a liquid state at various temperatures.
- For converting from true vapor pressure to Reid Vapor Pressure (RVP).
- For simple evaluation of refrigerated storage versus ambient temperature storage for LPGs.

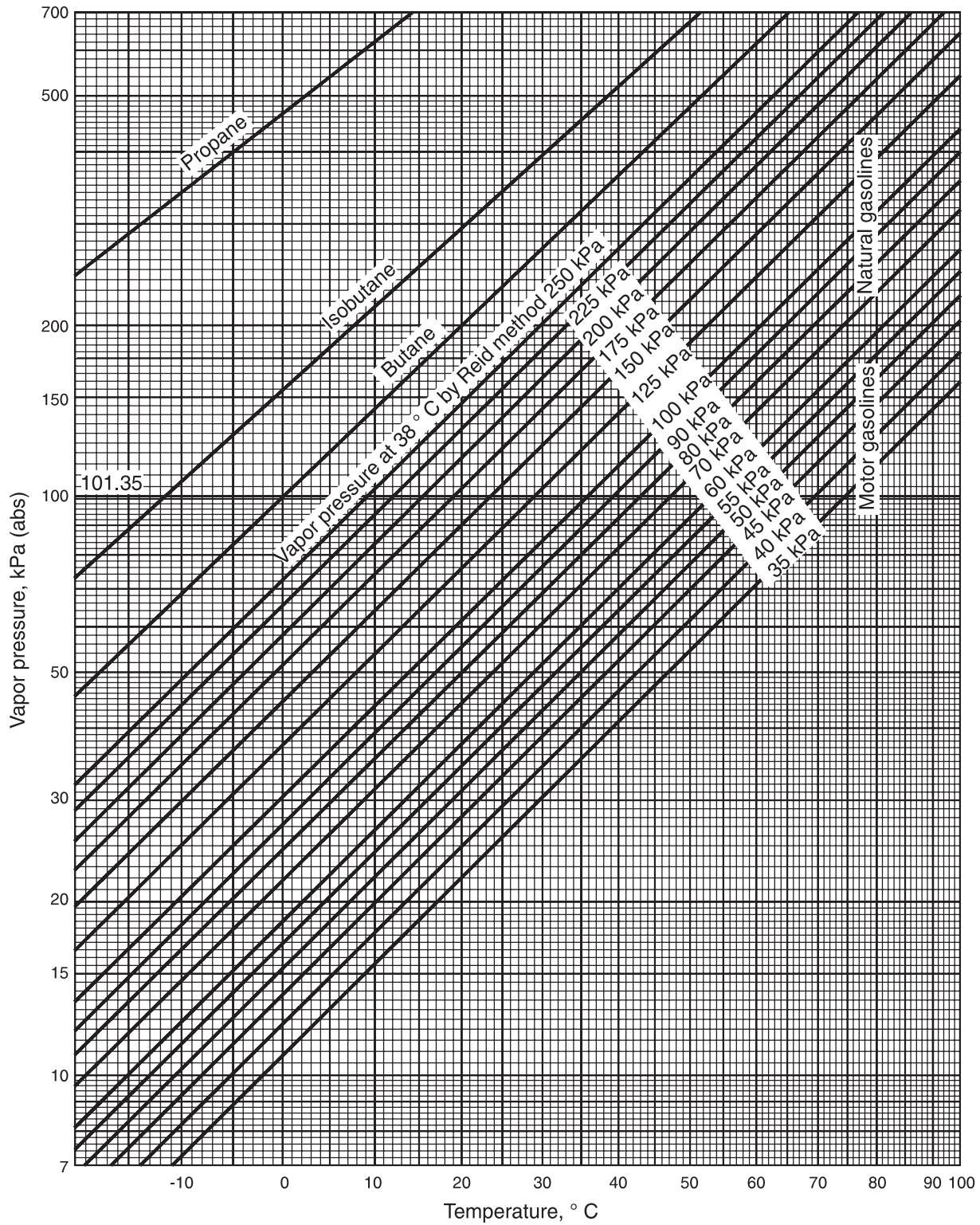
**Example 6-2** — Determine the TVP of a 83 kPa RVP gasoline. In addition, estimate the design pressure of a tank needed to store this same 83 RVP gasoline at a maximum temperature of 49°C. Using Fig. 6-4, a vertical line is extended upwards from the 38°C mark (38°C is used as the reference point for determining RVP) at the bottom of the chart to the intersection of the 83 kPa RVP line, read true vapor pressure of 91 kPa (abs). A vertical line is also extended from the 49°C mark to intersect the 83 RVP gasoline line. Now going horizontal, the true vapor pressure axis is crossed at approximately 125 kPa (abs). The storage tank should therefore be designed to operate at 125 kPa [25 kPa (ga)] or above. The design pressure of the tank should be a minimum of 10% above the operating gauge pressure or approximately 127 kPa (abs).

**Example 6-3** — Evaluate the options of refrigerated storage versus ambient temperature storage for normal butane. From Fig. 6-4 the vertical line is extended up from the 38°C (assumed maximum) mark to intersect the normal butane line at approximately 355 kPa (abs) [255 kPa (ga)]. The working pressure of the tank should be 255 kPa (ga) plus a 10% safety factor, or 280 kPa (abs). This same product could be stored in an atmospheric pressure tank if the product is chilled to 0°C. This temperature is determined by following the normal butane line down until it intersects the 100 kPa (abs) horizontal vapor pressure line. Reading down to the bottom scale indicates the storage temperature at 0°C. The pressurized tank would require more investment due to the higher working pressure of 380 kPa (abs) [280 kPa (ga)] and the thicker shell requirement. The refrigerated tank would require less investment for the tank itself, but an additional investment would be necessary for insulation and for refrigeration equipment which requires additional operating expenses. The economics of each type of storage system can be evaluated to determine which will be the most attractive.

The graphical method of converting from RVP to TVP is an approximation and is generally more accurate for lighter components. Crude oils with very low RVPs could vary significantly from this graphical approach. This is due to the fact that during the Reid test the highest vapor pressure materials tend to evaporate leaving a residue which has a lower vapor pressure than

FIG. 6-4

True Vapor Pressures vs. Temperatures for Typical LPG, Motor, and Natural Gasolines



CAUTION: This chart cannot be used to determine crude oil vapor pressure.

the original sample. Equation 6-3 was developed by A. Kremser in 1930 to relate the two vapor pressures at 37.8°C.

$$\text{TVP} = (1.07) (\text{RVP}) + 4.1 \quad \text{Eq 6-3}$$

Using this formula for the 83 kPa RVP gasoline example would calculate a 93 kPa (abs) TVP versus the 91 determined graphically. The RVP is less than the true vapor pressure at 37.8°C. Published data indicate the ratio of true vapor pressure to Reid vapor pressure may vary significantly, depending on the exact composition of the stored liquids. Ratios from 1.03 to 1.60 have been verified by test data.<sup>1,2</sup> Before entering the final design phase of any storage project, test data should be gathered on the fluid to be stored.

## TYPES OF STORAGE

### Above Ground

For operating pressures above 100 kPa (ga), design and fabrication are governed by the ASME Code, Section VIII.

**Spheres** — Spherical shaped storage tanks (Fig. 6-5) are generally used for storing products at pressures above 35 kPa (ga).

**Spheroids** — A spheroidal tank is essentially spherical in shape except that it is somewhat flattened. Hemispheroidal tanks have cylindrical shells with curved roofs and bottoms. Noded spheroidal tanks are generally used in the larger sizes and have internal ties and supports to keep shell stresses low. These tanks are generally used for storing products above 35 kPa (ga).

**Horizontal Cylindrical Tanks** — The working pressure of these tanks can be from 100 to 7000 kPa (ga), or greater. These tanks often have hemispherical heads.

**Fixed Roof** — Fixed roofs are permanently attached to the tank shell. Welded tanks of 80 m<sup>3</sup> capacity and larger may be provided with a frangible roof (designed for safety release of the welded deck to shell joint in the event excess internal pressure occurs), in which case the design pressure shall not exceed the equivalent pressure of the dead weight of the roof, including rafters, if external.

**Floating Roof** — Storage tanks may be furnished with floating roofs (Fig. 6-6) whereby the tank roof floats upon the stored contents. This type of tank is primarily used for storage near atmospheric pressure. Floating roofs are designed to move vertically within the tank shell in order to provide a constant minimum void between the surface of the stored product and the roof. Floating roofs are designed to provide a constant seal between the periphery of the floating roof and the tank shell. They can be fabricated in a type that is exposed to the weather or a type that is under a fixed roof. Internal floating roof tanks with an external fixed roof are used in areas of heavy snowfalls since accumulations of snow or water on the floating roof affect the operating buoyancy. These can be installed in existing tanks as well as new tanks.

Both floating roofs and internal floating roofs are utilized to reduce vapor losses and aid in conservation of stored fluids.

Environmental rules for new equipment restrict cone-roof tanks without vapor-recovery facilities to materials having a true vapor pressure at the tank temperature of less than 10.3 kPa(abs) and floating-roof tanks to materials of less than 76.5 kPa(abs).

Above 76.5 kPa(abs), a pressure vessel or vapor recovery scheme is mandatory. These rules should be considered minimum requirements. Toxic or odoriferous materials will need bet-

ter emission control than a floating-roof tank can provide. Local conditions sometimes call for such strict hydrocarbon emission limits that the use of floating-roof tanks comes under question. See Fig. 6-5 for common storage vessels.

**Bolted** — Bolted tanks are designed and furnished as segmental elements which are assembled on location to provide complete vertical, cylindrical, above ground, closed and open top steel storage tanks. Standard API bolted tanks are available in nominal capacities of 16 to 1600 m<sup>3</sup>, designed for approximately atmospheric internal pressures. Bolted tanks offer the advantage of being easily transported to desired locations and erected by hand. To meet changing requirements for capacity of storage, bolted tanks can be easily dismantled and re-erected at new locations.

**Specialty** — Pipe Storage (Fig. 6-7) — Pipe that is used specifically for storing and handling liquid petroleum components or liquid anhydrous ammonia must be designed and constructed in accordance with any applicable codes.

**Flat-Sided Tanks** — Although cylindrical shaped tanks may be structurally best for tank construction, rectangular tanks occasionally are preferred. When space is limited, such as offshore, requirements favor flat-sided tank construction because several cells of flat-sided tanks can be easily fabricated and arranged in less space than other types of tanks. Flat-sided or rectangular tanks are normally used for atmospheric type storage.<sup>1</sup>

**Lined Ponds**<sup>2</sup> — Ponds are used for disposal, evaporation, or storage of liquids. Environmental considerations may preclude the use of lined ponds for the storage of more volatile or toxic fluids. Linings are used to prevent storage liquid losses, seepage into the ground, and possible ground water contamination. Clay,

FIG. 6-5  
Seven Common Storage-Vessels for Low- and High-Pressure Services

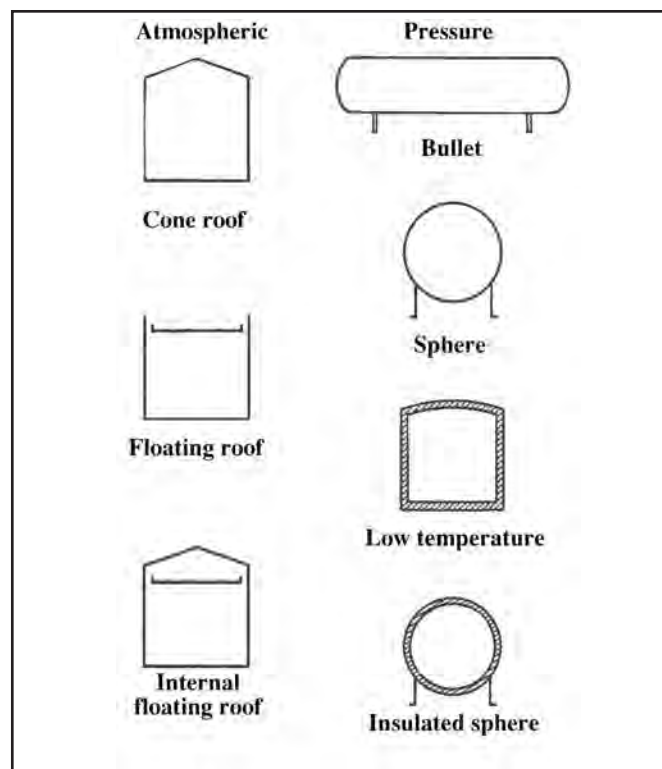
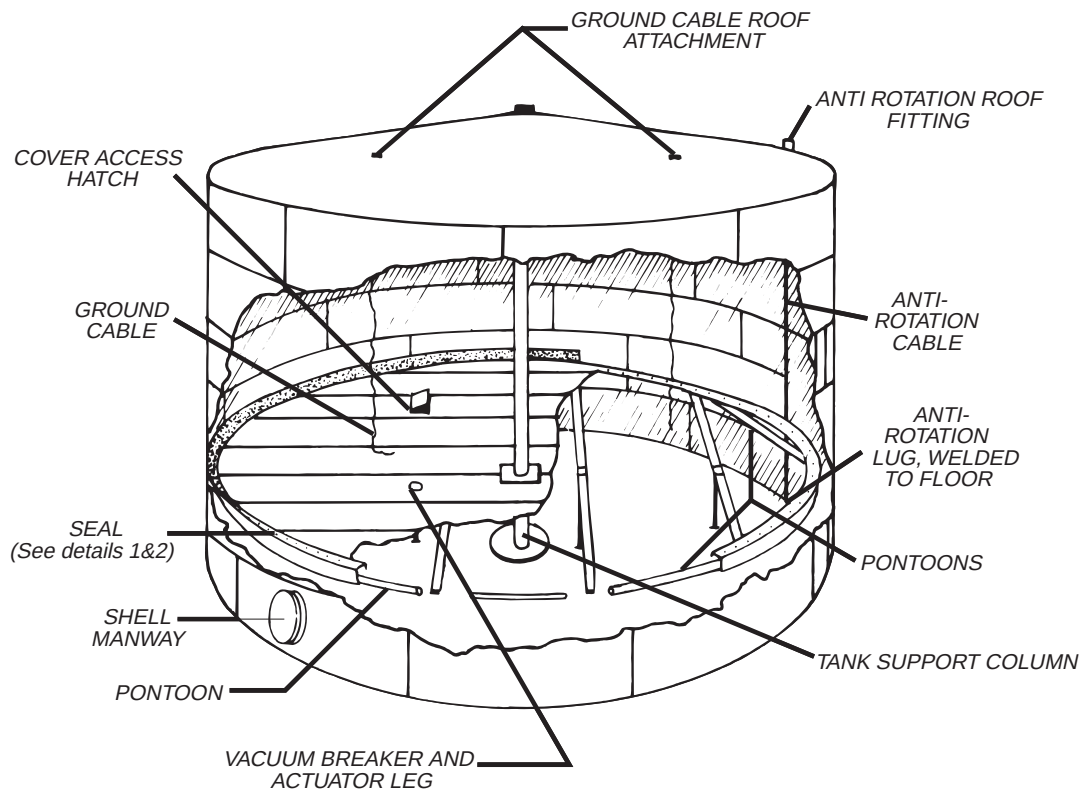


**FIG. 6-6**  
**Typical Arrangement of Internal Floating Roof Tank**

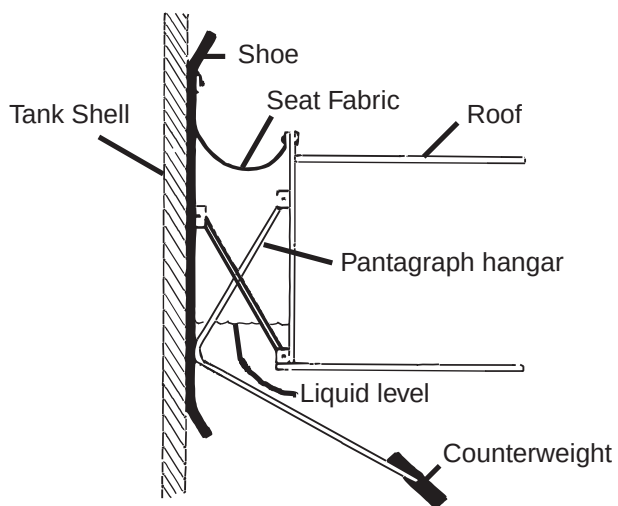


*(Also applicable to external floating roof tanks if dome roof is removed)*

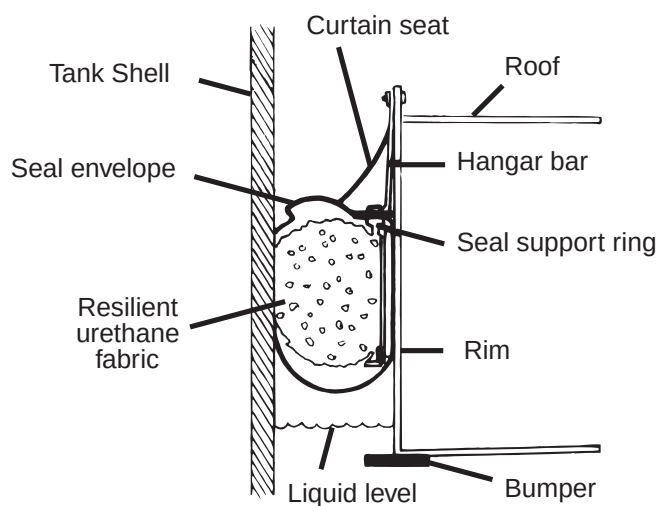
*Courtesy of CE Natco*

**Example Types of Seals for Floating Roof Tanks**

**Detail 1 - Shoe seal**



**Detail 2 - Tube Seal**



wood, concrete, asphalt, and metal linings have been used for many years. More recently, a class of impervious lining materials has been developed that utilize flexible synthetic membranes. Commonly used lining materials are polyvinyl chloride, natural rubber, butyl rubber, and Hypalon®. Polyethylene, nylons, and neoprenes are used to a lesser extent.

Some of the most important qualities of a suitable liner are:

- High tensile strength and flexibility.
- Good weatherability.
- Immunity to bacterial and fungus attack.
- Relative density greater than 1.0.
- Resistance to ultraviolet-light attack.
- Absence of all imperfections and physical defects.
- Easily repaired.

Leak detection sometimes must be built into the pond system, especially where toxic wastes or pollutants are to be stored. Types of leak-detection systems that are commonly used are underbed (French) drainage system, ground resistivity measurement, and monitor wells, and any combination thereof.

**Pit Storage** — Pit storage is similar to pond storage but is only used on an emergency basis. The use of this type of storage is limited by local, state, and federal regulations.

## Underground

Underground storage is most advantageous when large volumes are to be stored. Underground storage is especially advantageous for high vapor pressure products.

Types of underground storage are: (1) caverns constructed in salt by solution mining or conventional mining, (2) caverns constructed in nonporous rock by conventional mining, and

(3) caverns developed by conversion of depleted coal, limestone, or salt mines to storage.

**Solution Mined Caverns** — The cavern is constructed by drilling a well or wells into the salt and circulating low salinity water over the salt interval to dissolve the salt as brine.

The cavern may be operated by brine displacement of product, pumpout methods, vapor displacement, or as in the case of gas, by product expansion (see Figs. 6-8, 6-9 and 6-10).

Most solution mined caverns are operated using the brine displacement technique (Fig. 6-8). A suspended displacement string of casing is installed near the bottom of the cavern and product is injected into the annulus between the product casing (casing cemented at cavern roof) and the displacement casing, forcing brine up the displacement casing. The procedure is reversed for product recovery. In this type of operation, a brine storage reservoir is usually provided. Detail 1 of Fig. 6-8 provides the typical piping for the wellhead of an underground storage well.

Some solution mined caverns are operated “dry” by installing a pump at cavern depth either within the cavern or in a well connected to the cavern. Both submersible electric driven pumps and line shaft pumps (deep well vertical turbine pumps) are used for this purpose (see Fig. 6-9).

**Conventional Mined Caverns** — Conventional mined caverns can be constructed any place a nonporous rock is available at adequate depth to withstand product pressures. An engineer or geologist experienced in underground storage should evaluate any specific site for the feasibility of constructing underground storage. Most product caverns are constructed in shale, limestone, dolomite, or granite. This type cavern is operated “dry” (product recovered by pumping).

## Refrigerated Storage

The decision to use refrigerated storage in lieu of pressurized storage is generally a function of the volume of the liquid to be stored, the fill rate, the physical and thermodynamic properties of the liquid to be stored, and the capital investment and operating expenses of each type of system.

The parameters involved in selecting the optimum refrigerated storage facility are:

- Quantity and quality of product to be stored.
- Fill rate, temperature, and pressure of incoming stream.
- Shipping conditions for the product.
- Composition of the product.
- Cooling media (air, water, etc.) available.
- Availability and cost of utilities.
- Load bearing value of soil.

The proper choice of storage and the proper integration of the storage facility with the refrigeration facilities are important to overall economy in the initial investment and operating costs. Fig. 6-11 provides some general guidelines to use when selecting a storage system for propane.

When using refrigerated storage, the liquid to be stored is normally chilled to its bubble point temperature at atmospheric pressure. Refrigerated storage tanks normally operate at an internal pressure between 3 and 15 kPa (ga).

FIG. 6-7  
Pipe Storage

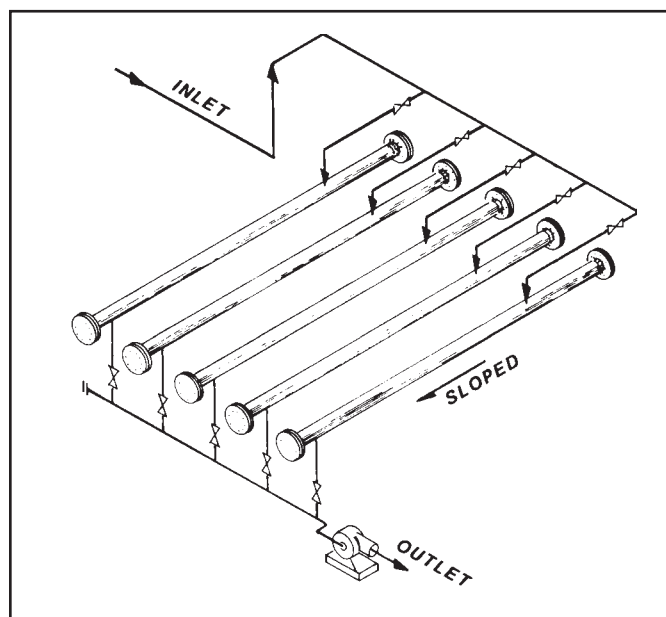
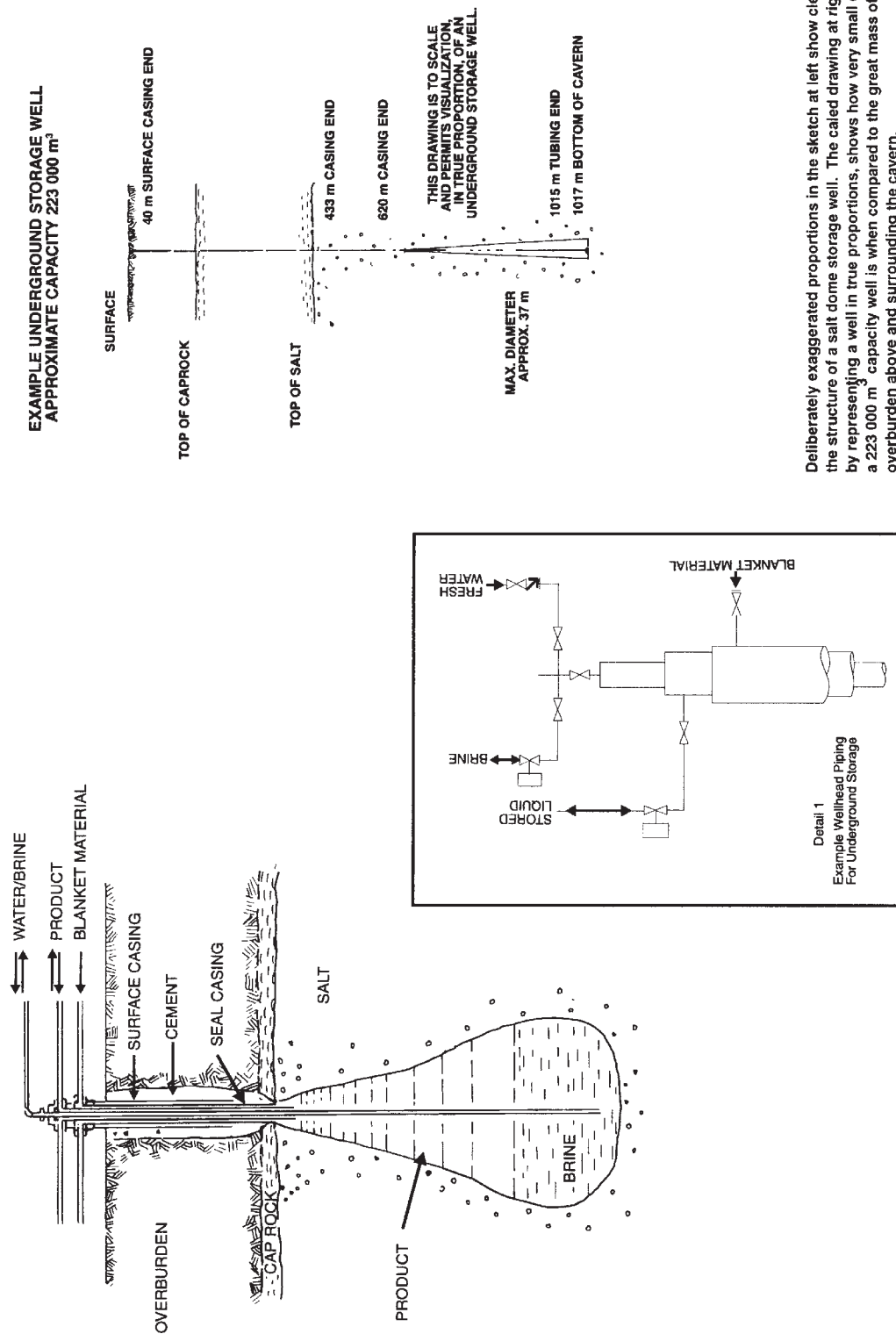


FIG. 6-8  
Brine Displacement Cavern Operation (Solution Mined Cavern)



Deliberately exaggerated proportions in the sketch at left show clearly the structure of a salt dome storage well. The called drawing at right, by representing a well in true proportions, shows how very small even a 223 000 m<sup>3</sup> capacity well is when compared to the great mass of overburden above and surrounding the cavern.