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Revision Memo

- 12/99** References have been updated. Appendix B has been rewritten to include reference to DP XIII-B and it has been renamed Appendix A. Appendices A, C and D have been deleted (now redundant). There have been some editorial changes to bring this DP in line with the references, and with lessons learned from consulting on recent problems and larger jobs.



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SCOPE

This section covers the selection of the type of atmospheric storage tank, determination of tankage volume, and requirements for associated tank equipment at refineries and chemical plants.

REFERENCES

DESIGN PRACTICES

Other Sections of Section XXII

Section XIII	Mixing Equipment
Section XV	Safety in Plant Design
Section XVI	Thermal Insulation

INTERNATIONAL PRACTICES

IP 3-2-2,	Foam System for Storage Tanks
IP 3-5-1,	Fill and Discharge Lines, and Auxiliary Piping for Storage Tanks and Vessels
IP 4-8-1,	Tank Foundations
IP 9-1-1,	Spacing and Dikes for Storage Vessels and Tanks
IP 9-4-1,	Atmospheric Storage Tanks
IP 9-7-1,	Accessories for Atmospheric Storage Tanks
IP 9-7-3,	Vents for Fixed Roof Atmospheric Storage Tanks
IP 9-7-4,	Internal Floating Roofs for Atmospheric Storage Tanks
IP 15-1-3,	Instruments for Storage Tanks and Vessels

API BULLETINS AND STANDARDS

1. API MPMS 3.1B, *Manual of Petroleum Measurement Standards Chapter 3 - Tank Gauging, Section 1B - Standard Practice for Level Measurement of Liquid Hydrocarbons in Stationary Tanks by Automatic Tank Gauging.*
2. API MPMS 4.4, *Manual of Petroleum Measurement Standards Chapter 4 - Proving Systems, Section 4 - Tank Provers* (API STD 1101, 2531, 2533, 2534).
3. API MPMS 19.1, *Manual of Petroleum Measurement Standards Chapter 19 - Evaporative Loss Measurement, Section 1 - Evaporative Loss from Fixed-Roof Tanks* (Supercedes BULL 2518).
4. API STD 620, *Design and Construction of Large, Welded, Low-Pressure Storage Tanks.*
5. API STD 650, *Welded Steel Tanks for Oil Storage.*
6. API RP 651, *Cathodic Protection of Aboveground Petroleum Storage Tanks.*
7. API RP 652, *Lining of Aboveground Petroleum Storage Tank Bottoms.*
8. API STD 653, *Tank Inspection, Repair, Alteration, and Reconstruction.*
9. API STD 2000, *Venting Atmospheric and Low-Pressure Storage Tanks Nonrefrigerated and Refrigerated.*
10. API PUBL 2210, *Flame Arresters for Vents of Tanks Storing Petroleum Products.*
11. API RP 2350, *Overfill Protection for Petroleum Storage Tanks.*
12. API BULL 2521, *Use of Pressure-Vacuum Vent Valves for Atmospheric Pressure Tanks to Reduce Evaporation Loss.*
13. API STD 2550, *Method of Measurement and Calibration of Upright Cylindrical Tanks*, (ASTM D1220) (ANSI Z11.197) (R 1992).
14. API STD 2555, *Method for Liquid Calibration of Tanks*, (ASTM D1406-65).
15. API MPMS 7.4, *Manual of Petroleum Measurement Standards Chapter 7 - Temperature Determination, Section 4 - Static Temperature Determination Using Fixed Automatic Tank Thermometers.*

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OTHER LITERATURE

1. FAST-TABLET Users Manual.
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3. *Safe Storage and Handling of Asphalts*, ER&E Report No. EE.85.E.83, December, 1983.
4. *Asphalt and Fuel Oil Plant Design Guide*, ER&E Report No. MERP.4M.73, December, 1973.
5. *Control of Hydrocarbon Emissions from External Floating Roof Tanks by Use of Secondary Seals*, ER&E Report EE.132E.79, November, 1979.
6. *FLEXICOKING Unit Feed Tankage*, EE Memo 81GE296, April 9, 1981.
7. *Crude Storage Tank Cleaning*, ER&E Report No. EE.124E.82, October, 1982.
8. *Tank Maintenance Guide*, ER&E Manual EETD 0050.
9. *Automatic Crude Oil Sampling Handbook*, ER&E Report No. EE.40E.84, May, 1984.
10. *Frangible Roofs - Are They Needed?* ER&E Report No. EE.36E.84, May, 1984.
11. *Frangible Roof Protection for Fixed Roof Tanks*, ESOC Communication 87-3.
12. *Crude Tank Mixing and Sludge Control Guide*, ER&E Report No. EE.18E.86, February, 1986.
13. *Guidelines for Minimizing Nonwithdrawable Tank Inventory*, ER&E Report No. EE.1M.86, August, 1986.
14. *Hydrocarbon Measurement Practices*, Exxon Company U.S.A. and Exxon Company International.
15. *Water Drawoff Equipment and Guidelines for Improved Plant Operation*, ER&E Report No. EE.4M.88, December, 1988.
16. *Hydrostatic Tank Gauging*, ER&E Report No. EE.5M.90, December, 1990.
17. *Secondary Containment Design for Leak Detection in Aboveground Storage Tanks*, ER&E Report No. EE.103E.91, December, 1991.
18. NFPA 30, *Flammable and Combustible Liquids Code*.
19. *Selection Guide for Storage Tank Emission Controls*, ER&E Report No. EE.35E.93.
20. MEFA: Minimum Emissions Facilities Assessment, Section III, *Emissions from Tankage*, ER&E Report No. EE.12E.92, February, 1992.
21. *Methods of Reducing the Permeability of Tank Dikes and Pits*, ER&E Report No. EE.30E.92, February 1992.
22. *Tanks 3.1 - Storage Tank VOC Emissions Estimating Tool*, ER&E Manual CPEE 162.
23. *Refining Oil Loss Manual*, ER&E manual EETP 048.
24. *Updated Guidelines for Preventing Electrostatic Ignitions*, ER&E Report EE.2M.98
25. *Section XIII-B, Asphalt Operations*, and *Section XIII-E, Hot Oil Tankage*, ER&E Safety Group's Safety Technology Manual (ER&E Intranet), 1999.
26. EPA Publication AP-42, *A Compilation on Air Emission Factors*, Chapter 7.1, US EPA, September 1997.
27. Exxon Blue Book, ER&E Manual EETD 011 (Metric) or EETD 012 (Customary).

Note: Refer to EXXINFO technical report database for future additions.

DEFINITIONS

See [Section XXII-A](#).

PRINCIPAL TYPES OF ATMOSPHERIC STORAGE TANKS

The two principal types of atmospheric storage tanks are fixed roof and floating roof. A brief description of each type follows:

FIXED ROOF TANKS

This type of tank has a fixed roof that is in the form of a cone or dome. The roof can be designed to be self-supporting in the smaller sizes, but is normally supported by columns in the larger diameter tanks. The tank operates with a vapor space, which changes in volume when the liquid level moves. Roof vents are provided to allow for vapor emission and to maintain the tank at atmospheric pressure.

Fixed roof tanks may be either inert gas-blanketed or vapor space enriched if they for example contain low vapor pressure stocks sensitive to degradation by oxygen or contain high flash stocks stored within 15°F (8°C) of their flash point.

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PRINCIPAL TYPES OF ATMOSPHERIC STORAGE TANKS (Cont)

▶ GEODESIC DOME ROOFS

The use of geodesic dome roofs (refer to **Figure 1**) offers several advantages. Geodesic dome roofs are self-supporting, i.e., no internal support columns are required, can be quite large [200 ft (61 m) diameter], and can be fabricated adjacent to the tank and lifted into place. They are commonly used to cover external floating roof tanks to prevent rainwater and/or snow infiltration. The roofs can be equipped with skylights, but care must be taken to specify window materials that are compatible with the product stored. When skylights are specified, a permanent accessway to the skylights should be provided. The geodesic domes are usually fabricated from aluminum. This creates a problem if the tank is used in inerted service (slight internal overpressure) since aluminum and the shell steel have different coefficients of expansion and properly sealing all the roof to shell support joints is difficult.

FLOATING ROOF TANKS

The floating roof tank is constructed so that the roof floats on the liquid surface. This eliminates the vapor space and greatly reduces vapor loss. The three principal types of floating roofs are single deck pontoon, double deck and internal floating roof. A brief description of each type follows:

Single Deck Pontoon Roof (See **Figure 2**) - The single deck pontoon roof consists of a flat center deck surrounded by pontoons that are divided radially into a number of compartments. Because the roof is exposed to the weather, adequate drainage facilities and buoyancy requirements must be provided per API 650. **IP 9-4-1** covers the additional requirements for sizes larger than 60 ft (18 m) in diameter. The design procedures in ER&E Report No. EE.23ERL.70 are still valid. External pan type (without pontoons) floating roofs are not acceptable due to the ease of sinking the roof.

▶ **Double Deck Roof** (See **Figure 2**) - Double deck roofs have some advantages over single deck roofs, although they are generally more costly. They have good resistance to wind-induced deflections, and there is little likelihood of overloading a double deck roof with rainwater, since only small quantities can collect on it. The water will quickly spill into the emergency drains even if the main drain is closed. Generally speaking, double deck roofs are used for large tanks [over 200 ft (61 m) in diameter] and must be used for tanks over 300 ft (91 m) in diameter (**IP 9-4-1**).

Internal Floating Roof (See **Figure 3**) - The internal floating roof is installed in a cone roof or geodesic dome roof tank rather than in an open top tank as with the single or double deck roofs. Internal floating roof tanks are generally used in lieu of conventional floating roof tanks: 1) when changing existing fixed roof tanks into services requiring floating roofs, 2) where excessive environmental loads due to rain, snow, and ice exist, and 3) when stock stored is sensitive to degradation by water which could enter through seals in conventional floating roof tanks. The fixed roof eliminates the need for roof drainage associated with conventional floating roofs. Such tanks are therefore especially well suited for cold locations, where maintenance of the open top tanks is a substantial expense. Exxon Engineering's first preference from safety considerations is the open top pontoon type floating roof tank; however, if internal floating roof tanks prove to be more attractive due to operating or economic considerations as described above, they are acceptable from a safety standpoint.

Two basic types of internal floating roofs are currently available:

1. **Aluminum Tubular Pontoon or Float Type Floating Covers** (**Figure 3**) - Tubular floating covers are of the non-contacting type, i.e., they are designed essentially as floating rafts and contain a vapor space of about 4 to 6 in. (100 to 150 mm) between the liquid and the roof deck. Primary sealing of the vapor space is accomplished by a peripheral rim edge angle, which projects into the liquid surface. For efficient sealing, the ring around the rim and other deck openings must project 6 in. (150 mm) into the liquid. The covers are constructed from thin aluminum sheeting which is supported on an aluminum grid framework and air-filled tubular aluminum pontoons. Alternatively, rectangular aluminum floats filled with rigid polyurethane are used. Another acceptable design uses a honeycomb panel between two thin aluminum layers ("Sanborn" roof).
2. **Pan Roof** - These roofs are constructed of steel in the form of a pan. They are inherently unstable as they are provided with no reserve buoyancy and no drainage capability. Because of problems with roof sinking, tanks with pan roofs are no longer permitted (**IP 9-7-4, Par. H.2.a**).

Internal floating roof tanks are considered equivalent to open top, pontoon roof tanks for spacing. Foam facilities shall be provided to supply total surface coverage, e.g., equivalent to coverage provided for cone roof tanks. Evaluation of design may be necessary for tanks greater than 150 ft (45 m) in diameter and for storage temperatures greater than 150°F (66°C). For storage applications at temperatures up to 180°F (82°C) and at diameters greater than 150 ft (45 m), the use of external single deck steel pontoon or double deck floating roofs is recommended.

Due to service switches, environmental, or oil loss considerations, it may be necessary to retrofit an existing cone roof tank with an internal floating cover. The designer should be aware that the utilization factor of a retrofitted cone roof tank could be greatly reduced with the installation of an internal floating roof. One way to increase the utilization of these tanks is to add an additional course to the tank shell and place a dome roof on top.

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PRINCIPAL TYPES OF ATMOSPHERIC STORAGE TANKS (Cont)

Many proprietary designs are offered by vendors. New roof designs are continuously being developed and experience data with existing designs are being accumulated. Because of this, it is advisable to obtain the latest status before proceeding with an internal floating cover installation by contacting your TANKAGE SPECIALIST.

SELECTION OF THE TYPE OF ATMOSPHERIC TANK

For a given application, the designer will have to choose from among the types of atmospheric storage tanks described above, based on the service requirements, the characteristics of the material to be stored and any other special local considerations. Note especially that local laws governing air pollution control, fire protection and safety must be taken into account to insure that the storage facilities selected will comply.

The following guidelines concern the choice between fixed roof and floating roof. If a floating roof tank is chosen, selection among single deck pontoon, double deck, or internal floating cover should be based on the information given on these types under PRINCIPAL TYPES OF ATMOSPHERIC STORAGE TANKS, above.

EXTERNAL FLOATING ROOF TANKS

Floating roof tanks should be used for the services listed below. This summary is based on experience, safety considerations and economic studies.

Static Accumulators - Stocks that are classified as intermediate vapor pressure static accumulators per [Section XV-B, Minimizing the Risks of Fire, Explosion or Accident](#).

Flash Point - Stocks which are to be stored at temperatures within 15°F (8°C) of their flash points, or higher.

Type of Stock - All crude oil stocks.

Tank Size - All tanks with diameters exceeding 150 ft (45 m), if they are to contain low-flash stocks (flash point 100°F [38°C] or below). Within recent years, low flash stocks have been stored in floating roof tanks regardless of diameter to limit fire risk and environmental concerns.

Oxygen Sensitivity - High vapor pressure stocks which are sensitive to degradation by oxygen (e.g., coker naphtha). For this service, the toroidal type of seal is preferred. (Low vapor pressure stocks, which are oxygen-sensitive, should be stored in fixed roof tanks with nitrogen or inert gas blanketing.)

Other - Special considerations may require storage in fixed roof tanks or fixed roof tanks with internal floating roofs. Examples include the use of cone roof tanks with vapor recovery for high RVP stocks due to stringent hydrocarbon emissions requirements. Also, due to a combination of snow loads (which dictated the need for fixed roofs) and location within an earthquake zone (which raised the concern of floating roofs hanging up due to out of roundness tank walls), the crude tanks for the Valdez terminal were installed as vapor-blanketed, cone roof tanks.

INTERNAL FLOATING ROOF TANK

Fixed roof tanks with internal floating covers are generally used in lieu of conventional floating roof tanks when:

1. There is a need to change service of an existing fixed roof tank to one that requires a floating roof tank.
2. Excessive environmental loads due to rain, snow and ice exist.
3. The stock stored is sensitive to degradation by water, which could enter through seals in conventional floating roof tanks.
4. It is economically more feasible.

From a tank spacing standpoint, where equivalency to an external floating roof tank is desired, the use of internal floating covers is limited to tanks with a maximum diameter of 150 ft (45 m).

FIXED ROOF TANKS

Fixed roof tanks are used for all atmospheric storage where floating roofs are not required or not practical. They are also used where inert gas blanketing or vapor space enrichment is required. Examples of these situations are:

1. Low vapor pressure stocks subject to stringent hydrocarbon emission requirements or sensitive to degradation by oxygen.
2. High flash stocks stored within 15°F (8°C) of flash point (hot tanks).
3. Areas of high seismic activity where there is a concern that floating roofs may hang up due to out of roundness of tank walls.
4. Areas of heavy snow loads like Alaska, which dictate a need for fixed roof tanks.
5. Future restrictions in environmentally stringent areas may require fixed roof tanks, vapor balanced with loading facilities and vapor recovery. Floating roof designs may not be adequate even if equipped with secondary seals.
6. For products that cling to the shell walls and would prevent the free movement of a floating roof, for example asphalt.

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BASIC DESIGN CONSIDERATIONS

Tankage design involves determining the number and sizes of tanks required to support refinery operations. Various tankage services include feed tankage, intermediate tankage, component blendstock tankage and finished product tankage. Siting tankage within the refinery borders is also a major design consideration. Evaluation parameters include safety, economic and environmental factors. Other factors to be considered in the overall evaluation of tankage needs follow.

DESIGN VALUES FOR INNAGE AND OUTAGE

The following table represents the minimum values for innage and outage to be used for computing the gross tankage volume. The innage value will vary according to the nozzle size [nominal 12-in. (300 mm) nozzles were used] and nozzle configuration used but the table below provides reasonable figures to be used for planning purposes. Refer to ER&E Report No. EE.1M.86 for minimum tank innage for specific nozzle sizes and configurations. For new tanks, the designer needs to be specific regarding net (working) volume requirements. Refer to [IP 9-4-1](#), [Par. 6.2](#) for definition of shell height definition and the potential need for shell extensions. Refer to [IP 9-7-1](#), [Par 8.4](#) for overflow slots requirement. For existing tanks, specific details of roof design need to be verified.

TYPE OF TANK	INNAGE, in. (mm)	OUTAGE, in. (mm) ⁽⁴⁾
External Floating Roof ⁽³⁾	36 (910)	18 (460)
	30 (760) ⁽¹⁾	12 (300) ⁽²⁾
Internal Floating Roof ⁽³⁾	31 (790)	18 (460)
	25 (635) ⁽¹⁾	12 (300) ⁽²⁾
Fixed Roof	22 (560)	18 (460)
		12 (300) ⁽²⁾

Notes:

- (1) Applies when remote level instrumentation is used.
- (2) Applies when the tank is equipped with a reliable system of centralized level instrumentation and valve control.
- (3) Outage for floating roof tanks can be significantly greater for certain floating roof designs, e.g., double deck, foam dam details, etc. unless the top of the tank shell is extended.
- (4) Outage amounts may need to be increased in earthquake zones to provide additional freeboard to minimize "sloshing" overflow from tankage.

ECONOMIC TANK SIZING

The following guidelines apply to tank size, number, and height/diameter.

Size - In general, the cost per barrel (cubic meter) of tankage decreases with increasing tank size (subject, of course, to limitations on maximum practical size). However, operating flexibility is generally greater with a larger number of smaller tanks. Tank sizes can range from a low of about 10 kB to over 500 kB in a refinery.

Number - At least two tanks are usually provided for each finished product service. The actual number provided is a function of the following factors - total volume requirements, the need to separate rundown tankage (from a unit or blender) from certified on-spec finished product tankage, parcel size of shipments, customs requirements, and tank maintenance.

Height vs. Diameter - The maximum tank height should be specified based on soil conditions, local fire codes and structural design considerations such as maximum shell thickness, in order to minimize the amount of land area required. An exception to this is that for floating roof tanks, the height to diameter ratio should not exceed 1.0, to permit roof access by way of a rolling ladder.

For a large tank, a typical height is 48 or 56 ft (14.5 or 17 m). Heights have traditionally been specified in 8 ft (2.4 m) increments to match the dimension of standard shell plates. However, other plate widths are available, and tank contractors may suggest using other plate widths if economical (wider plates minimizes welding requirements at the expense of more steel). Tank heights of 64 ft (19.5 m) are occasionally used. Greater tank heights are possible for refrigerated LPG/LNG services due to the low density of the stored liquid.

STRUCTURAL DESIGN CONSIDERATIONS

The primary structural requirements governing the design, fabrication, erection and inspection of atmospheric storage tanks are covered in the International Practices. The International Practices are based on, and are supplemental to, API Standard 650, *Welded Steel Tanks for Oil Storage*. In locations where API Standards are mandatory, or where more stringent local codes exist, such standards and codes must be followed.

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BASIC DESIGN CONSIDERATIONS (Cont)

TANK HEATING

The tank contents should always be maintained at a temperature at least 15°F (8°C) above the pour point, or sufficient to keep the kinematic viscosity from exceeding 300 cSt (300 mm²/s), whichever is greater. If the minimum ambient temperature is cooler than this, tank heaters should be specified. Calculation of heat losses from tanks and design of tank insulation are covered in [Section XVI, Thermal Insulation](#).

TANK MIXERS

- Services for which mixing equipment should be specified are listed below, with an explanation of the purposes served by the mixers. Design and/or selection of mixing equipment is covered in [Section XIII, Mixing Equipment](#), and [APPENDIX A](#).

Two types of mixers are generally recommended: 1) The side entry propeller (SEP) mixer and 2) The jet mixer. The jet mixer is not suitable for mixing high viscosity fluids like heavy heating oils and asphalt, but it is more suitable for automotive diesel oil and lighter materials. The SEP mixer is appropriate for all applications. The choice between the two is usually made based on economics.

Butterworth P43 machines can also be used in place of jet mixers. However, the installed cost of these machines is much higher than a jet nozzle and they should only be considered if a very short mixing time is required. They are not in wide use but they are excellent for controlling sludge buildup and resuspending settled sludge in crude tanks.

Crude Tanks - Side entry propeller type mixers should be specified for all crude tanks. The mixers serve the following purposes:

1. To prevent the deposition of wax from waxy crudes.
2. To allow slop to be blended with crude.
3. To maintain BS&W in suspension.

Product tanks that contain a stock produced by the blending of two or more components and/or additives should be equipped with mixers. Mixing can be accomplished by a jet nozzle with a recirculation system or by SEP mixer. The final selection should be based on economics. The mixing is required for the following reasons:

1. To prevent stratification of components within the tank.
2. To allow for re-mixing after the addition of a component to adjust an off-test blend.
3. To prevent temperature stratification in large hot oil tanks [above 265°F (130°C)].

Blend Stock Tanks - The rundown line should be equipped with a jet nozzle. This will ensure uniform blend stock quality. A recirculation system is not usually required.

Intermediate Tanks - The rundown line should be equipped with a jet nozzle. If, however, the downstream unit can be upset by feed that is not consistent in quality, a recirculation system or propeller mixer should be used instead. The selection should be based on economics.

LOCAL SITE CONDITIONS

Elevation above sea level is important, because it directly affects the true vapor pressure limitation placed on stocks stored in atmospheric tankage. At sea level the maximum allowable true vapor pressure is 13 psia (90 kPa absolute). For each 1,000 ft (300 m) elevation above sea level, this value must be reduced by 0.5 psi (3.5 kPa).

Ambient Temperature - The maximum and minimum ambient atmospheric temperatures should be determined. This information is needed to classify the hydrocarbon into the appropriate vapor pressure and flash point class.

TANKAGE REALLOCATION

Changes in product slate, product movement pattern, or parcel sizes may indicate the desirability of re-allocating existing tankage to different services. A detailed check of what changes are required to the existing tankage and piping system is needed to establish the practicality of the proposed changes. Although tank reallocation often appears desirable when comparing available vs. required tankage by service, layout and piping constraints often combine to make the cost of tank reallocation very high. When existing tankage is allocated to new product classes, e.g., high flash cone roof tanks converted to low flash service, diking capacity and spacing criteria require re-evaluation for the new service.

STOCK CLASSIFICATION

The liquid to be stored must be classified into the appropriate static and vapor pressure class, according to the criteria given in [Section XV-B, Minimizing the Risks of Fire, Explosion or Accident](#). This information is required, to determine whether a floating roof tank must be specified for safety reasons.

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BASIC DESIGN CONSIDERATIONS (Cont)

ENVIRONMENTAL IMPACT ON TANK BOTTOM DESIGN

- Secondary containment and leak detection are now required in many parts of the world to protect the environment from accidental leaks and spills. Of primary concern is a leak from the bottom of an aboveground storage tank.

For bottom leaks, there are two designs now being recommended. They are:

- Double steel bottom tank design. This is the most flexible one since it can be used for existing tanks and in new tank construction. However, it is more costly and seldom used for new construction.
- Impermeable membrane installed in the tank foundation beneath the tank bottom. This design is suitable only for new construction and is described in [IP 4-8-1](#), *Tank Foundations*.

For tank farm spills, the issue of secondary containment encompasses the entire diked impounding area. This brings into question the permeability of the soil comprising the impounding area and dikes and its adequacy to protect the environment beyond the refinery grounds. The trend in legislation is to require the installation of impermeable membranes to enclose these areas.

DESIGN PROCEDURES

SIZING CRUDE TANKAGE

Crude is delivered to a refinery by either tanker or pipeline. Refinery crude storage is necessary to prevent unplanned runouts and costly tanker delays and occasionally to meet government-mandated compulsory storage requirements.

There are three basic ways to determine optimum crude storage requirements when received from tankers: crude circuit simulation model, Tankage and Blending Evaluation Tool (FAST-TABLET), and the parcel size plus advance and delay method. Compulsory storage requirements would be additive to the working volume.

Crude Circuit Simulation Model simulates the crude supply system. This model is applicable for regional studies and is normally run by regional logistics or supply departments.

- FAST-TABLET** (Facilities Assessment Simulation Tool - Tankage and Blending Evaluation Tool) is an Exxon developed computer stochastic simulation tool. In the oil movements and storage area, it can be used to evaluate crude and product tankage, and associated marine facilities (number of berths, loading lines, loading rates). Optimization is achieved by entering facilities data into the model, running alternative cases, and developing economics outside of the model runs. Typical FAST-TABLET runs simulate several years of operations.

- Parcel Size plus Advance and Delay** is an approximate method that should be used with engineering judgement. It sizes crude tankage through the use of experience factors involving the number of advance and delay days associated with moving crude from a particular source to the refinery. The total barrels of tankage required for crude volume is arrived at by the following empirical formula:

$$\text{Crude Volume} = \text{Maximum Parcel Size} + \text{Pipestill Stream Day Feed Rate} \times (\text{Advance Days} + \text{Delay Days} + \text{Pumping and Settling Days})^*$$

* The total number of days normally ranges from 5 to 15.

The terms are described as follows:

- Maximum Crude Parcel Size** is the volume of the largest anticipated crude receipt at the refinery.
- Days of Advance and Delay** represent the number of days, which correspond to the anticipated deviations between a planned arrival time and an actual arrival time. The number can be determined for rough estimates on the previous experience of the refinery. Advance days are associated with shipments arriving ahead of schedule and require crude tank space. Delay days are associated with shipments arriving late and require crude tank stock to maintain pipestill supply.
- Pumping and Settling Time** - The pumping time is the time required for the tanker to discharge the maximum parcel size. Most tankers have pumping capability to discharge their cargo within 24 hours. The settling time is the time required to settle the crude and draw off the water. Settling time depends on the degree of cleaning of the crude tanks; typical settling times in clean tanks is 1/2 to 2 days. This time increases should there be a sludge problem due to either the receipt of heavy or special crudes, or if existing mixing facilities are not efficient or are underpowered.

This technique can also be used to size crude tankage for refineries that are supplied by a pipeline. The maximum parcel size would correspond to the maximum pipeline receipt size, and the advance and delay days would be equivalent to the anticipated outage time, which can be obtained from the pipeline operators.

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Crude Sampling - The increased importance of oil loss control has placed accurate and reliable determination of the sediment and water content (BS&W) and the average density of crude oil transfers among the prime concerns of the petroleum custody transfer operation. Sampling techniques applied to tanks and ships' compartments do not give reliable or representative samples. Sampling of crude oil flowing in a pipeline has been shown to be effective provided careful attention is given to the pipeline conditions, sampling system design, sample handling, and transfer of sample for lab analysis. Refer to ER&E Report No. EE.40E.84 for information on the design of a sampling system.

SIZING PRODUCT TANKAGE

The basic variables which set the requirements for net product tankage volume are working storage requirements (includes seasonality), unit turnaround protection and compulsory storage requirements. Each of these is discussed below.

To determine the total volume, one calculates the minimum volume necessary for working storage and compares this with the volume required for turnaround protection. The larger number is then the design capacity for the product tankage. Compulsory storage is normally added to this, to give the total volume of product tankage that must be provided. Blend stock, sometimes referred to as component tankage, is considered part of the product tankage.

A spreadsheet is a convenient format to use for evaluating product tankage requirements. Although the spreadsheet is not a dynamic model or stochastic simulation of the production and distribution system, it does provide the tankage planner and designer with a deterministic method for rapidly seeing how tankage requirements for each product are affected by changing key variables, e.g., advance/delay factor, production rate, etc. The spreadsheet is very applicable to evaluating changes to existing refinery operations since experience is available on the level of fluctuations in the distribution system.

Each refinery will have its own set of priorities, specific scenarios to handle, and desired flexibility. Consequently, it is not possible to present a list of rules. However, the following items should be checked in developing an allocation plan for product tankage:

- Provide storage for each product for maximum parcel size as defined by Refinery. Size may vary according to product.
- Provide advance/delay/safety margin for:
 - Early ship arrival.
 - Late ship arrival.
 - Customs clearance.
 - Lab testing if on-line analyzer values not acceptable.
 - Batch blending time.
- Consider two tanks for each major product to allow blending during loading.

$$\text{Product Tankage (Net)} = \text{Maximum Parcel} + (\text{Advance} + \text{Delay} + \text{Safety}) \text{ days} \times \text{Stream Day Production Rate}$$

SIZING COMPONENT TANKAGE

Sizing of component tankage is based on the specific blending flexibility required by a refinery.

Typical considerations are:

- Maximum component volume for the product batch. Product batch size is normally one product tank volume.
- An allowance for "advance/delay" in blending/shipping schedules. An example would be 3 days for Mogas and 2 days for distillate, which is easier to blend.
- Turnaround storage to cover short repeatable events such as reforming unit regeneration. Unit turnarounds (30 to 60 days) are generally scheduled in complementary unit blocks to eliminate large storage requirements.
- Blocked operation of certain units to maximize yields but which result in discontinuous component production.

Working Net Storage Requirements - Working (net) tankage is composed of three basic components. The first is maximum parcel size, or the amount of tankage required for refining and transportation operations when production and demand are in balance. The second, referred to as vessel advance/delay factor, allows for imbalance that occurs due to variations from ideal demand and transportation conditions. This portion is expressed in terms of equivalent unit production days and is calculated from experience numbers supplied by the refinery or affiliate. The total advance/delay will normally range from 5 to 10 days.

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The third portion is that additional tankage volume required to contain (during the off-season) excess production of a product that has a seasonal variation in demand. During the period of higher than average annual demand, this pre-stored product is withdrawn from inventory to supplement current production. Over the years, the need for seasonal storage of products at the refineries has decreased in general. Product rate variations can be handled in other ways than storage at the refinery, such as adjusting the refinery's running plan to be in line with the seasonal product demand pattern. In addition, marketing tankage and other supply system flexibilities are utilized to minimize the need for tanks and inventory to handle seasonal product rate swings.

The minimum working volume is calculated as follows:

Minimum Working Volume = Maximum Parcel Size

$$+ (\text{Calendar Day Throughput}) \times (\text{Days Advance} + \text{Days Delay})$$

$$+ (\text{Calendar Day Throughput}) \times (365 \text{ CD/yr}) \frac{(\% \text{ Seasonality})}{100}$$

Note: Typical volume units are Bbl or cubic meters.

The maximum parcel size is typically used in the above calculation. On occasion, however, the arrival frequency of vessels calling for average size parcels is such that tankage is required for several average size parcels (since this volume is greater than the maximum single parcel).

Unit Turnaround Protection - This tankage is required to cover demands during the period when the production unit is down. This volume is calculated as follows:

$$\text{Volume} = (\text{Number of Turnaround Days}) \times (\text{Calendar Day Throughput})$$

Before this volume is established, the economics of alternative methods of providing product during the turnaround period should be examined. For some locations the following approaches have proved more economical than investments in tankage.

1. Exchange arrangements with other refineries.
2. Supplementing supplies by obtaining product from another circuit refinery.
3. Increasing tankage availability at marketing distribution locations.

Compulsory Storage Requirements - Compulsory storage of products (for use in time of crisis) is a government requirement at certain locations. Normally, these volumes cannot be figured into the net design capacities and are over and above that required for working tankage or for turnaround protection. Some countries also require compulsory storage of crude. The rules for calculating compulsory storage requirements are very site specific and often require interpretation by the local affiliate.

Number of Product Tanks - No simple technique is available to determine the individual sizes and number of tanks to make up the final total product volume. An approach that takes into account the basic guidelines listed below should be used.

1. Specify at least two tanks per grade if the grade is produced continuously from a unit or blender. This is because the rundown stream should not be filling a tank while a shipment is being loaded out of the same tank.
2. Match product parcel sizes with net tankage volume. This will help to prevent situations where one parcel requires the use of one whole tank and a part of another. This situation ties up the remaining usable space in the second tank and is not desirable if it is likely to occur often.
3. Depending on the frequency of simultaneous by-land and marine movements of the same product, a separate by-land day tank may be required to separate by-land and marine shipments. These day tanks are often part of a separate marketing operation.

SIZING INTERMEDIATE TANKAGE

Intermediate tankage is storage for an intermediate product that will be used as feed to another unit. The following guidelines should be used for developing volume requirements for intermediate tankage:

Turnaround Schedule - Determine the turnaround schedules for the producing and consuming units involved. This schedule should consider mechanical maintenance as well as process related operations such as catalyst regeneration if applicable.

Volume Requirement - Determine the volume required to store surplus production of the upstream unit during the turnaround of the downstream unit, and to provide feedstock for the downstream unit during the turnaround of the upstream unit. This will depend on which unit has the longer turnaround and whether they occur at the same time. The greater of the two volumes is the volume required. Alternative uses or sources for the intermediate product are sometimes more economically attractive than providing dedicated tankage for this purpose.

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GROSS TANKAGE VOLUME

The previous section described procedures for determining net tankage volume for various refinery streams at 60°F (15°C). The volume occupied by thermal expansion of the stored fluid and the unusable volume inherent in all tank designs need to be added to net volume to quantify tank dimensions. These additions are covered below.

Innage and Outage Allowance - These values reflect non-usable portions of tank contents.

Innage is minimum static inventory in a storage tank. This is the liquid remaining below the lowest normal pumping level. It is expressed as the distance from the lowest bulk liquid level to the tank base line. See **BASIC DESIGN CONSIDERATIONS** for recommended innage and outage values.

Outage is the space left at the top of a storage tank to provide a safety margin to prevent spillover during filling. It includes an allowance for the floating roof pontoon and an allowance to give the operator time to take corrective action. It is expressed as the distance measured from the top of the tank shell to the maximum allowable bulk liquid level. Generally, 18 in. is allowed for working volume unless a motor operator fitted with a high level cutout is provided to close the inlet valve which permits reduction to 12 in. Alternatively, high level alarm/cut out points are defined in time units to allow for operator intervention. For example, on a recent project, the first high-level alarm point (HLA) was at 30 minutes before overfilling at the maximum filling rate. This HLA was generated by the tank gauging instrument. A second independent instrument alarm, high high level alarm (HHLA) was provided at 25 minutes before overfill. For specific applications, setting alarm points should be reviewed with the Safe Operations Committee (SOC) or equivalent.

Caution: Refer to specific tank details to determine outage and maximum fill levels. Shell extensions are sometimes used to avoid having floating roof seal weather shield, secondary seal, or primary seal extend above the shell/shell extension in normal operation.

Thermal Expansion Requirements - This is an allowance resulting from temperature changes of the contents during storage. Frequently, it is considered as outage, however, it is recommended that the working tankage volume be determined for the maximum tankage holdup temperature using the hot material specific gravity for volume calculation. **Figure 4** is provided to determine this value. Similar data is available in the *Blue Book*.

Tank Size - Specify the largest single tank (if possible; otherwise minimize the number of tanks) which will meet the volume requirement.

TANK ACCESSORIES

The basic requirements for tank accessories to be included in the tank specification are summarized below:

Tank Nozzles

NOZZLE SERVICE	FLOATING ROOF TANK		FIXED ROOF TANK	
	NOZZLE SIZE	TYPE NOZZLE	NOZZLE SIZE	TYPE NOZZLE
Steam ⁽¹⁾	All	API Low	All	API Low
Condensate	All	API Low	All	API Low
Water Drawoff	All	API Low	All	API Low
Oil Inlet	< 12 in. (300 mm)	API Low	All	API Low
Oil Inlet	≥ 12 in. (300 mm)	Flush	All	API Low
Oil Outlet	< 12 in. (300 mm)	API Low	< 8 in. (200 mm)	API Low
Oil Outlet	≥ 12 in. (300 mm)	Flush	≥ 8 in. (200 mm)	API Low (Elbow Down)
Jet Nozzle	All	API Low	All	API Low

Notes:

- (1) When the design requires that the steam inlet nozzle be elevated above the condensate nozzle, the steam inlet nozzle may be specified as an API Standard type nozzle up to and including 6-in. (150 mm) diameter.
- (2) When jet nozzles are used in floating roof tanks, it should be specified that the roof be designed so that there is no interference between the jet nozzle and floating roof when the roof is in the lowest landed position.
- (3) The maximum allowable size for an API type nozzle is 30-in. (760 mm).
- (4) The largest allowable flush type nozzle size is 24-in. (610 mm). If additional capacity is required, multiple flush type nozzles should be used.

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- (5) The minimum allowable size water drawoff for crude tanks is 6-in. (150 mm).
- (6) Consider the use of high or floating suction in unit feed and distillate product tanks to minimize water entrainment. (Note that a fixed high suction will increase tank innage.)
- (7) The inlet and outlet nozzles must be designed per API 650 and the International Practices such that the piping design satisfies allowable loads on these nozzles. This requirement should be part of the tank specification.
- (8) Although the API permits the use of flush type nozzles down to an 8-in. (200 mm) diameter, API low nozzles are recommended in 10 in. and smaller sizes in product tankage due to product contamination considerations.

Water Drawoff - All tanks in hydrocarbon service shall be provided with a minimum of one water drawoff connection using an API low type nozzle. If a cone bottom up tank is used with a diameter greater than 20 ft (6 m), a water drawoff sump is required. Cone bottom down tanks do not require a water sump. For these tanks, the water is collected from the low point in the center of the tank using an elbow down pipe drawoff line. The vast majority of tanks are of the cone bottom down type. Various schemes to perform this operation automatically have had varied success over the years. One of the major problems is detecting the oil/water interface.

WATER DRAWOFF EQUIPMENT

The existence of an immiscible water phase or suspended oil water phase at the bottom of atmospheric storage tanks is quite common. It is important that this accumulated water be periodically removed as its presence increases tank bottom corrosion and promotes biological growth. In the past, this water was removed manually, that is, the water drawoff valve was opened, the outflow observed until free oil appeared, and then the valve was shut. Semi-automatic drain valves, which take advantage of the difference in density between the oil and water, have been used but have not gained wide acceptance due to difficulties experienced in sensing certain oil/water emulsion interfaces and failure of the valves to operate reliably.

Closed drawoff systems from individual tanks to one or more dedicated slop tanks have proven quite successful at locations where adequate tankage exists.

Improvements to the basic unassisted manual drawoff operations are obtainable using commercially available technologies which offer reductions in manpower requirements, minimize the quantity of oil drawn from the tank with the water, and reduce operator exposure to the products.

Over and above the water drawoff line required per the International Practices, there are recommended facilities that permit the recovery of oil remaining in the drawoff line from the previous operation that would otherwise be drained to grade. Alternative options include the following:

- Hard pipe the water drawoff line to a local catch basin for eventual oil recovery in the waste water treating system.
- Provide a hand pump and recycle line to pump the line contents back to the tank prior to water drawoff. A sight glass in the line allows the operator to see when the oil is displaced and water is present.
- Provide a small local drum to contain the contents of the drawoff piping. The drum would then be periodically emptied via a vacuum truck, or the oil recycled to tankage.
- Locate the apex of the floor cone off-center, i.e., near to the WDO nozzle to minimize oil in the WDO line.

Current designs should consider a combination of in-tank and in-line hydrocarbon/water interface detection technologies. The in-tank interface measurements are utilized to indicate when a drawoff operation is required and the quantity of water within the tank. The in-line interface detection is utilized to terminate the operation when the first traces of oil are present in the drawoff line. The operation can be made semi-automatic with the use of an on/off type control valve in the drawoff line. Two basic methods may be used: one in conjunction with tank level gauging (**Figure 5**) and the other in conjunction with a totaling flow meter (**Figure 6**); both cases use a % oil switch and an on/off control valve in the drawoff line. Refer to ER&E Report No. EE.4M.88 entitled *Water Drawoff Equipment and Guidelines for Improved Plant Operation* for further details. **Caution:** Verify reliability for specific applications.

Roof Drains for External Floating Roof Tanks - Roof drains are provided to remove rainwater from the top of floating roofs. See **Figures 7** and **8**. Drains are usually jointed articulated pipes or hoses. Design is per API 650. In addition, the capacity of the drain shall be such that the maximum accumulation occurring on the roof membrane during the maximum design rainfall conditions is less than 1 in. (25 mm). This must be accomplished when the roof is in the lowest floating position.

The preferred roof drain is shown in **Figure 7** with the use of a high-grade flexible hose. These hoses contain a flexible stainless steel carcass and an impervious outer layer consisting of a thermoplastic or other material. They provide a repeatable "lay" pattern, minimizing the potential for hose damage during roof travel. One supplier of high-grade flexible hose is Coflexip and Services Incorporated of Houston, Texas.

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Articulated pipe drains are susceptible to corrosion at the ball races in the swivel joints. Flexible Rigid/Pivot drains avoid the corrosion problem by achieving flexibility through "pivots" which enclose short flexible hoses. One supplier of the Flexible Rigid/Pivot drain is HMT Corporation of Houston Texas.

Roof draining is normally a manual operation. The bottom drain valve is left closed to avoid spilling product in the event a leak develops in the articulated pipe drain or hose. Where rainfall is expected to exceed 10 in. in 24 hours, automatic roof drainage should be provided. This is done by installing a special ball valve in place of the manual shutoff valve. This valve will automatically open when exposed to water and close when exposed to hydrocarbon that is lighter than water.

The following are roof drain valves that are commercially available:

- Ludlam Sysco (Russel) Ball Valve, Systems and Components Ltd., Wiltshire, England
- Fushiman Type A103-1ADB Water Drain Valve Fushiman Co., Ltd. Tokyo, Japan
- HMT Checkmate Hydrocarbon Sensing Valve HMT, Inc., Houston, Texas
- Belfield Decantation Valve, Dewmark Products, St. Charles, Illinois

Floating roofs are sometimes provided with emergency drains. The emergency drain will allow water to pass through to the hydrocarbon side of the roof and settle to the bottom of the tank in the event the drain line plugs. Emergency drains are usually provided on all double deck roofs and permitted on single deck roofs where the pontoon area is at least 50% of the roof area.

Freeze protection for roof drains is an important consideration in cold climates. Some suggestions in this regard and in order of preference are:

- Electrically heat trace and insulate valve and piping outside the tank.
- Add anti-freeze to the drain system. Must replace anti-freeze after each use.
- Crack open block valve at grade during freezing weather. Develop and implement written operating procedures, which will minimize any leakage of hydrocarbon and will call for opening and closing the valve at the appropriate times.

Floating Roof Tank Seals - These seals serve several functions. They close the annular rim space of the roof, assist with centering of the floating roof yet permit normal roof movement, maintain lightning strike protection, control evaporation loss, and minimize atmospheric pollution. A seal system can consist of one or two separate seals. The first seal is called the primary seal. The installation of a secondary seal above the primary seal can significantly reduce emissions by providing an additional barrier through which vapors must pass. In addition, some seal systems include a weather shield. EPA Publication AP-42 provides methods of estimating hydrocarbon vapor releases with various seal arrangements. In the U.S., secondary seals are becoming required emission control technology on external floating roof tanks storing volatile hydrocarbon liquids. Refer to *Environmental Considerations in Tankage Design* for further details on tank seals.

Roof Vents - Roof vents are used to allow inbreathing and outbreathing of the vapor space below the roof. Inbreathing is caused by drawing product out of a tank or by a drop in temperature which causes the gases in the vapor space to contract. Outbreathing is caused by filling a tank and thereby displacing the vapor volume with liquid volume. A rise in the vapor space temperature also results in outbreathing by virtue of expanding the gases occupying the vapor space. Changes in barometric pressure will also result in either inbreathing or outbreathing.

Other sources of outbreathing are air agitation and fire exposure. Air agitation to mix tank contents is not recommended based on environmental and safety considerations. However, provision must be made to relieve pressure buildup, which may occur due to fire exposure at or near the tank. Such heating effect would tend to boil off additional vapors and expand them to such an extent that tank design pressure would be exceeded if additional emergency venting is not provided. In most large tanks, no additional emergency vents are required since fixed roof tanks are built in accordance with API 650, which calls for a weak roof-to-shell seam design.

Refer to API Standard 2000 for estimating venting requirements for atmospheric storage tanks. Note that if the API-2000 venting requirement is used to calculate inert gas make-up rates to prevent vacuum, a very high inert gas supply rate will result. This is due to the built-in conservatism to protect the tank roof and shell from vacuum, and the fact that open vents are very cheap to build big. A detailed study of the actual temperature, pressure and product movements should be completed to set inert gas make-up rates.

Fixed roof tanks are provided with either pressure-vacuum (PV) vents or open type vents. The PV vent is used on all fixed roof tanks, which contain products with a flash point below 100°F (38°C) or where the product temperature will normally be within 15°F (8°C) of the product's flash point. For environmental reasons (odor abatement), some locations now require fixed roof tanks storing hot product to use a PV vent. If this hot product would tend to plug a PV vent, the PV vent shall be purged with a gas injected at the vent (**IP 9-7-3, Par. 3.2.b.**). It is suggested to consider heat tracing the vent as well.