EMISSION REDUCTION OPTIONS FOR FLOATING ROOF TANK FITTINGS

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ABSTRACT

Significant advances have been made in both understanding the magnitude of emissions from floating-roof deck fittings and identifying emission reduction options. As a result of a testing program that was performed by Chicago Bridge and Iron Co. for the American Petroleum Institute, loss factors were measured for different types of floating-roof deck fittings.

This paper describes the types of deck fittings used on floating roof tanks, the emission calculation procedure, the test method used to measure the deck-fitting loss factors, and the results of the tests. The paper highlights the emission reduction options for slotted guidepole fittings and includes a benefit analysis that demonstrates the effectiveness of these options.

1.0 INTRODUCTION

This paper focuses on evaporative losses from the deck fittings of External Floating-Roof Tanks (EFRTs) and Covered Floating-Roof Tanks (CFRTs). The deck-fitting loss factors presented are based on the results of a recent testing program that was sponsored by the American Petroleum Institute (API) and performed by Chicago Bridge & Iron Technical Services Company. These loss factors currently appear in draft API Manual of Petroleum Measurement Standards, Chapter 19.2 [6]*, scheduled to be published by mid-1996. Some of these loss factors may change from their current values as the draft document is finalized.

1.1 Floating Roof Tank Types

It is useful to first understand the types of floating-roof tanks for which there are published loss calculation procedures. The types of floating-roof tanks include:

- External Floating-Roof Tanks (EFRTs),
- Internal Floating-Roof Tanks (IFRTs), and
- Covered Floating-Roof Tanks (CFRTs).

The basic components of a floating roof include: (a) a floating deck; (b) an annular rim seal attached to the perimeter of the floating deck; and (c) deck fittings that penetrate the floating deck for operational purposes.

1.1.1 External Floating-Roof Tanks

External Floating-Roof Tanks (EFRTs) are vertical cylindrical vessels which do not have a fixed roof over the top of the tank, but which utilize an external floating roof that rests on the product liquid surface. The external floating roof is typically constructed of welded steel plates. Minimum requirements for the design of external floating roofs are given in API Standard 650, Appendix C [1].

External floating roofs are typically of two general types:

- Pontoon Floating Roofs (see Figure 1), and
- Double-Deck Floating Roofs (see Figure 2).

Pontoon floating roofs, Figure 1, incorporate buoyancy chambers that assist in keeping the roof floating, even under heavy water or snow loads. One type of design uses an annular ring of pontoons as the outer perimeter of the floating deck. In this design, the center single deck area is designed to balloon upward to contain the product vapors that are generated from ambient heating of the product liquid surface under the floating roof.

* Numbers in brackets refer to the numbered references listed at the end of this paper.

The amount of surface heating, however, is reduced by the insulating effect of the double-deck in the pontoon area and by the ballooning effect of the center single-deck.

Double-deck floating roofs, Figure 2, incorporate two decks which cover the entire area of the floating roof. Vertical bulkheads are used to support the upper deck and to divide the space between the decks into separate liquid-tight compartments. The double-deck floating roof provides good stability, but the rain water load carrying capacity is less than the pontoon floating roof. The top deck, which extends over the entire area of the floating roof, provides an insulating air space between the decks and thus minimizes ambient heating of the product liquid surface.

External floating roofs are typically of welded construction, and the deck seams are thus not a source of evaporative loss.

1.1.2 Covered Floating-Roof Tanks

Covered Floating-Roof Tanks (CFRTs) result from retrofitting an EFRT with a fixed roof at the top of the shell. This effectively converts the EFRT to an internal floating roof tank, but retains the heavier type of floating roof construction that is typical of a floating roof built in accordance with API Standard 650, Appendix C [1]. A CFRT incorporates the same vapor space venting as that of an internal floating-roof tank, which is in accordance with API Standard 650, Appendix H [1].

Some CFRTs utilize a fixed roof that is a self-supporting aluminum dome roof, which is of bolted construction. The minimum requirements for the design of aluminum dome roofs are given in API Standard 650, Appendix G [1].

1.1.3 Internal Floating-Roof Tanks

Internal Floating-Roof Tanks (IFRTs) are vertical cylindrical vessels which have a fixed roof over the top of the tank and incorporate a lightweight floating roof that floats on the surface of the product. The minimum requirements for the design of the lightweight internal floating roofs are given in API Standard 650, Appendix H [1].

The fixed roof may be either "column-supported" (i.e., with support columns in the tank) or "self-supporting" (i.e., without support columns). To minimize the occurrence of a combustible air-vapor mixture in the tank vapor space, (i.e., the space between the floating roof and the fixed roof), circulation vents are installed at the top of the tank shell and on the fixed roof to provide natural circulation of air through the tank vapor space. Such tanks are commonly referred to as "freely vented" IFRTs.

Internal floating roofs are of two general types:

- Welded internal floating roofs, and
- Bolted internal floating roofs.

Bolted internal floating roofs are constructed by joining sheets or panels of deck material utilizing a mechanical means that includes bolting. Bolted deck seams are an additional source of evaporative loss on these types of internal floating roofs.

1.2 Deck Fitting Types

There are various types of fittings used on a floating roof deck that allow for operational functions, but which can be a source of evaporative loss since they require an opening in the deck. The most common types of deck fittings used on EFRTs or CFRTs that require openings in the deck are described below.

1.2.1 Access Hatches

Figure 3 shows a typical access hatch. An access hatch is used to provide for passage of workers and materials through the floating roof deck for construction and maintenance. The access hatch includes a cover that rests directly on the well. A gasket may be used between the cover and the well to reduce evaporative loss. The cover may be bolted to the well to further reduce evaporative loss.

1.2.2 Gauge-Hatch/Sample Wells

Figure 4 shows a typical gauge-hatch/sample well. Gauge-hatch/sample wells are used to provide access for hand gauging or sampling the product in the tank. This deck fitting is typically located below the gauger's platform and is fitted with a cover that may be opened by a cord from the gauger's platform. The cover may be fitted with a gasket to reduce evaporative loss.

1.2.3 Gauge-Float Wells

Figure 5 shows a typical gauge-float well. This fitting has a cover that rests on the well and incorporates a float that is supported by the product inside of the well. The float is connected by a cable or tape that passes through the cover to an automatic gauging system. A gasket may be used between the cover and the well to reduce evaporative loss. The cover may be bolted to the well to further reduce evaporative loss.

1.2.4 Rim Vents

Figure 6 shows a typical rim vent. Rim vents are normally supplied only on tanks equipped with mechanical-shoe primary seals. The rim vent is connected to the rim vapor space and releases any excess pressure or vacuum that is present. Rim vents typically incorporate weighted pallets, which may rest on gasketed surfaces to reduce evaporative loss. Such vents open only when the pressure or vacuum overcomes the weight of the pallet.

1.2.5 Vacuum Breakers

Figure 7 shows a typical vacuum breaker. Vacuum breakers are used to equalize the pressure beneath the floating roof with the pressure above the floating roof when the floating roof is either being landed on its legs or being floated off of its legs. Vacuum breakers are fitted with a cover that rests on the well. A gasket may be used between the cover and the well to reduce evaporative loss.

The cover is opened by a guided leg that extends from the cover downward and which comes into contact with the tank bottom when the tank is being emptied, just prior to the point at which the deck legs contact the tank bottom. Some vacuum breakers have a leg that is adjustable to permit changing the floating roof level at which the leg contacts the tank bottom.

1.2.6 Deck Legs

Figure 8 shows a typical deck leg. Deck legs provide support for the floating roof when it is landed on the tank bottom. Deck legs typically incorporate an adjustable pipe leg that passes through a slightly larger diameter vertical pipe sleeve. The sleeve is welded to the floating-roof deck and extends both above and below the deck. Steel pins pass through holes in the sleeve and leg to permit height adjustment.

To reduce evaporative loss, some deck legs are covered with a boot that encloses the portion of the deck leg that extends above the floating-roof deck. Alternatively, some deck legs incorporate a wiper seal or gasket to reduce the evaporative loss that occur between the leg and its sleeve.

One type of adjustable gasketed deck leg is shown in Figure 14. This deck leg incorporates a wiper seal that covers the annulus between the outside of the deck leg and the inside of the leg sleeve. In this design, the leg sleeve extends below the floating-roof deck and provides the required support when the floating roof lands in its low position. The top of the deck leg incorporates a locking bar that can be engaged in a latch attached to the top of the leg sleeve so that the floating roof can land in its high position for maintenance, cleaning and inspection work below the floating roof. An advantage to using this type of deck leg design, as opposed to using a boot, is the ease of changing deck leg positions without requiring the removal and replacement of the boot. For large diameter floating roofs that incorporate many deck legs, this can help operating personnel quickly and easily change the landing position settings of all of the deck legs.

1.2.7 Deck Drains

Decks of external floating roofs incorporate drain systems to permit drainage of rainwater or melted snow. Either open or closed drainage systems may be used.

Closed drainage systems carry water from the surface of the floating-roof deck to outside of the storage tank through a flexible or articulated piping system or through a hose that is located below the floating roof in the product space. Since product does not enter a closed drainage system, there is no associated evaporative loss.

Open drainage systems, on the other hand, permit drainage of water from the surface of the floating-roof deck directly into the product. Since open drainage systems require an opening in the floating-roof deck that connects directly with the product space, they have an associated evaporative loss.

Open drainage systems can only be used on double-deck floating roofs and incorporate either flush drains or overflow drains. Flush drains have a drain opening that is flush with the top surface of the floating-roof deck. Overflow deck drains (see Figure 9) incorporate an extension above the floating-roof deck that limits the maximum amount of water that is permitted to accumulate on the deck and thus is used to provide emergency drainage of excess water from the deck.

Some open deck drains incorporate a slit fabric seal that provides partial closure, except when rainwater is draining into the product, and thereby reduces evaporative loss. As rainwater flows through the open deck drain, the slit fabric opens to provide the required drainage area.

1.2.8 Unslotted Guidepole Wells

Figure 10 shows a typical unslotted guidepole well. The primary function of a guidepole is to prevent rotation of the floating roof as it rests on the stored product surface. In certain cases it has also been used to provide an access to hand gauge or sample product from within the guidepole. In these cases, openings are provided at the bottom of the unslotted guidepole to permit the product in the guidepole to communicate with the product in the tank. However, since the product in the guidepole does not freely mix with the product in the tank, the composition and liquid level of the product in the unslotted guidepole may not be representative of the product in the tank.

As a result of a recent API-sponsored testing program [12, 13, 14, 15], a number of evaporative loss control features for unslotted guidepole wells were identified and tested. These loss control features include:

- well gasket,
- pole wiper, and
- pole sleeve.

The well gasket is located between the top of the well and the sliding cover. The pole sleeve attaches to the sliding cover and extends downward into the product, completely surrounding the exterior of the unslotted guidepole. The pole wiper consists of a gasket

material that spans the gap between the opening in the sliding cover and the exterior of the guidepole.

All of these loss control features may be used individually or in combination. The loss factors for certain combinations of these features is discussed in Section 2.2.

1.2.9 Slotted Guidepole/Sample Wells

Figure 11 shows a typical slotted guidepole/sample well. A slotted guidepole provides operating personnel with a means to hand gauge or sample product from within the guidepole. Perforations are provided in the guidepole, typically overlapping slots, along its vertical length to allow the product in the guidepole to freely mix with the product in the tank. Thus, the liquid level, composition and temperature of the product within the guidepole are representative of the product in the tank.

As a result of a recent API-sponsored test program [12, 13, 14, 15] a number of evaporative loss control features for slotted guidepole/sample wells were identified and tested. These loss control features include (see Figure 12):

- well gasket,
- pole wiper,
- pole sleeve,
- float, and
- float wiper.

The float with wiper (see Figure 12) rests on the product surface inside of the guidepole. The location of the float wiper is typically below the pole wiper, unless multiple float wipers are used on the float. In this case, at least one float wiper is typically located below the pole wiper. Some floats incorporate a hinged cover (see Figure 13) through which the product level may be gauged or product samples may be taken without removing the float from the guidepole.

All of these loss control features may be used individually or in combination. The loss factors for certain combinations of these features is discussed in Section 2.2.

2.0 EMISSION CALCULATION METHOD

The total evaporative loss, L_t, from a floating-roof tank is a sum of the withdrawal loss, L_w, and the standing storage loss, L_s. Although the withdrawal loss can be important, this paper focuses primarily on the standing storage loss since this is typically the major component of the total evaporative loss.

The withdrawal loss, L_w, results when product is withdrawn from a floating-roof tank. As the floating roof level decreases, product clings to the inside surface of the tank shell and to the vertical support columns of the fixed roof, if used in an IFRT. When the

floating roof passes downward and exposes these areas, the volatile portion of the product clingage evaporates rapidly, resulting in evaporative loss. Some reduction in product clingage can be achieved by the use of rim seals that provide a wiping action on the inside surface of the tank shell. The withdrawal loss varies with tank operating practices. Industry-wide experience has found that this loss is often small, except in cases of high throughput that results in frequent tank turnovers (i.e., greater than about 10 turnovers per year), or in cases of significant product clingage, such as may occur with high viscosity crude oil.

The standing storage loss, L_s, occurs from the rim seals, deck fittings, and deck seams. The standing storage loss, L_s, may be determined from Equation 1:

$$L_s = (F_t)(P^* M_v K_c) \tag{1}$$

Equation 1 involves the product of two terms:

- **First Term, (F_t)**
  The first term pertains only to floating-roof construction parameters (e.g., rim seal system type, deck fitting types, and roof seam construction type) and environmental parameters (e.g., ambient wind speed). The total floating-roof loss factor, F_t, may be determined from Equation 2:

  $$F_t = F_r + F_f + F_d \tag{2}$$

  where: F_r is the total rim-seal loss factor; F_f is total deck-fitting loss factor; and F_d is the total deck-seam loss factor.

- **Second Term, (P^* M_v K_c)**
  The second term pertains only to the product characteristics and involves the vapor pressure function, P^*, the vapor molecular weight, M_v, and the product factor, K_c. The product factor, K_c is 1.0 for refined products and single-component products, and is 0.4 for crude oil products [2, 5, 6].

The vapor pressure function, P*, is defined by Equation 3:

$$P^* = \frac{(P / P_a)}{\left[1 + \left(1 - (P / P_a)\right)^{0.5}\right]^2} \tag{3}$$

where P is the product vapor pressure at the bulk liquid temperature and P_a is atmospheric pressure. For convenience, Table 1 lists the values of the vapor pressure function, P*, at various product vapor pressures, P, for an atmospheric pressure of 14.7 psia.

2.1 Rim-Seal Loss Factors

The total rim-seal loss factor, F_r, can be determined from Equation 4:

$$F_r = K_r D \tag{4}$$

where K_r is the rim-seal loss per tank diameter factor and D is the tank diameter.

The rim-seal loss per tank diameter factor, K_r, can be determined from Equation 5:

$$K_r = K_{ra} + K_{rb} V^n \tag{5}$$

where the rim-seal loss factors, K_{ra}, K_{rb} and n, are given in draft API Publication 2517 [2] as a function of tank construction and rim-seal system type.

For floating-roof tanks that have a fixed roof (i.e., IFRTs and CFRTs), the value of V in Equation 5 is zero, resulting in Equation 6:

$$K_r = K_{ra} \tag{6}$$

Rim-seal loss factors are available from API Publication 2517 [2] for both average-fitting and tight-fitting rim seals. For example, Figure 15 presents the rim-seal loss factors for average-fitting mechanical-shoe primary seals with rim-mounted secondary seals at ambient wind speeds of 5, 10 and 15 mi/hr. In the future, as a result of the API Loss Factor Certification Program [17], rim-seal loss factors may become available for specific proprietary rim-seal systems.

2.2 Deck-Fitting Loss Factors

The total deck-fitting loss factor, F_f, can be determined from Equation 7:

$$F_f = \left[(N_{f1}K_{f1}) + (N_{f2}K_{f2}) + \ldots + (N_{fk}K_{fk})\right] \tag{7}$$

where: N_{fi} is the number of deck fittings of a particular type; K_{fi} is the deck-fitting loss factor for the particular type of deck fitting; and i is the fitting type number (i = 1, 2, ..., k).

The deck-fitting loss factor for a particular type of deck fitting, K_{fi}, can be determined from Equation 8:

$$K_{fi} = \left(K_{fai} + K_{fbi}(K_v V)^{m_i}\right) \tag{8}$$

where the deck-fitting loss factors, K_{fai}, K_{fbi}, and m_i, are a function of the type of deck fitting and the construction details.

For EFRTs, as a result of an API-sponsored test program [8], a deck-fitting wind-speed correction factor, K_v, has been developed to account for the fact that the wind speed at a floating-roof deck fitting is less than the ambient wind speed at the tank site. The value of the deck-fitting wind-speed correction factor, K_v, that should be used in Equation 8 is listed below in Equation 9:

$$K_v = 0.7 \qquad (9)$$

This value was developed to represent typical conditions which occur at deck fittings on EFRTs over the full range of floating roof levels and of deck fitting locations.

For floating-roof tanks that incorporate a fixed roof (i.e., IFRTs and CFRTs), the value of V in Equation 8 is zero, and Equation 8 becomes Equation 10:

$$K_{fi} = K_{fai} \qquad (10)$$

Deck-fitting loss factors, K_{fa}, K_{fb} and m, are listed in draft API MPMS, Chapter 19.2 [6] for a wide range of deck-fitting types and construction details. Table 2 lists deck-fitting loss factors, K_f, for those deck-fitting types and construction details used on EFRTs and CFRTs, at wind speeds of 0, 5, 10 and 15 mi/hr. In the future, as a result of the API Loss Factor Certification Program [17], deck-fitting loss factors may become available for specific proprietary deck fittings.

The typical number of specific types of deck fittings used on a floating-roof deck can vary with the tank diameter. Tables are included in draft API MPMS, Chapter 19.2 [6] that are similar to those in API 2517 [2] and API 2519 [5] which provide information on the typical number of deck fittings of each type used on EFRTs and CFRTs.

2.3 Deck-Seam Loss Factors

Floating roofs used on EFRTs and CFRTs are of welded construction. The total deck-seam loss factor, F_d, is zero for this type of floating roof construction, as shown by Equation 11:

$$F_d = 0 \text{ (for welded floating roofs)} \qquad (11)$$

3.0 DECK-FITTING LOSS FACTOR TEST METHOD

3.1 Wind Tunnel Test Facility

The deck-fitting loss factors, K_f, listed in draft API MPMS, Chapter 19.2 [6] were measured in the Wind Tunnel Test Facility at the CBI Engineering and Development Center at Plainfield, Illinois.

Figure 16 is a photograph and Figure 17 is a schematic of the Wind Tunnel Test Facility. The wind tunnel is 29 ft. long and has a 3 ft. square cross section. It incorporates four test sections, each 5 ft. long for simultaneously testing 4 separate deck fittings. Each of the deck fittings being tested is a full-scale deck fitting mounted on a test vessel that rests on a digital platform scale. The deck fittings extend above the test vessels into the wind tunnel. The ambient wind effect on the exposed portion of the deck fittings is simulated by the air flowing through the wind tunnel. Air flow from a blower passes through a transition section and an air distribution system prior to passing over the deck fittings. The deck-fitting loss factor is determined from the weight loss readings.

3.2 Zero Wind Test Facility

The zero-wind-speed deck-fitting loss factors, K_{fa}, were measured in a separate Zero Wind Test Facility at the CBI Engineering and Development Center at Plainfield, Illinois.

Figure 18 is a photograph and Figure 19 is a schematic of the Zero Wind Test Facility. The Weight Loss Test Method is used to measure deck-fitting loss factors under conditions simulating those in the vapor space of IFRTs and CFRTs (i.e., near zero air flow rate). This test method involves mounting the deck fitting on a test vessel that is filled with a volatile test liquid. The test vessel is suspended from a load cell that is used to continuously measure the weight loss due to evaporation. The deck-fitting loss factor is determined from the weight loss readings.

3.3 Loss Factor Test Protocols

As part of the API Loss Factor Certification Program [17], test protocols have been prepared that will be used to measure deck-fitting loss factors for specific equipment [7]. These test protocols were developed from the experience gained in the recent API-sponsored test program [10, 11, 12, 13, 14, 15] to measure deck-fitting loss factors.

4.0 DECK-FITTING LOSS FACTOR TEST RESULTS

The results of the recent API-sponsored test program [12, 13, 14, 15] were used to develop the deck-fitting loss factors that appear in draft API MPMS, Chapter 19.2 [6]. Table 2 lists the loss factors of EFRTs at wind speeds of 0, 5, 10 and 15 mi/hr, as well as the deck-fitting loss factors of CFRTs.

Table 2 lists the deck-fitting loss factors for unslotted guidepole wells and slotted guidepole/sample wells. This table indicates that for both unslotted and slotted guidepoles it is possible to incorporate construction details that significantly reduce their deck-fitting loss factors. For example, for a slotted guidepole/sample well at an ambient wind speed of 10 mi/hr, the deck-fitting loss factor for the uncontrolled (i.e., not utilizing any of the loss control features listed in Table 2) is 3,565 lb-mole/yr, whereas the fully-controlled (i.e.,

incorporating all of the loss control features listed in Table 2) is only 46 lb-mole/yr. This is a reduction of nearly 99 percent.

5.0 DECK-FITTING LOSS REDUCTION OPTIONS

For an EFRT, evaporative losses during standing storage occur only from the rim seal and the deck fittings, since the deck seams are welded. The relative loss contribution from the rim seal and the deck fittings can be determined by comparing the rim-seal loss factors in Figure 15 with the deck-fitting loss factors in Table 2. It can be seen that the evaporative loss contribution from a guidepole fitting, either unslotted and slotted, that does not incorporate effective loss control construction details is considerably more than the evaporation loss contribution from the rim-seal.

For example, from Figure 15 for a 100 ft. diameter EFRT at a wind speed of 10 mi/hr, the total rim-seal loss factor is 200 lb-mole/yr. In comparison, from Table 2 for a slotted guidepole/sample well that does not incorporate effective loss controls at a wind speed of 10 mi/hr, the deck-fitting loss factor is 3,565 lb-mole/yr, or about 18 times the total rim-seal loss factor. Thus, it is important to evaluate the options available for reducing the total deck-fitting loss factor.

5.1 Description of Sample Case Numbers 1 Through 4

To evaluate the loss control effectiveness of alternative deck-fitting construction details, sample calculations of the total-deck fitting loss factor were performed for the following 4 cases:

- Case 1: EFRT With Slotted Guidepole,
- Case 2: EFRT With Unslotted Guidepole,
- Case 3: CFRT With Slotted Guidepole, and
- Case 4: CFRT With Unslotted Guidepole.

Each of these cases were evaluated for only a pontoon floating roof, since a double-deck floating roof gives similar results.

For each of these four cases, 5 subcases were evaluated where the loss control construction details of certain deck fittings were progressively improved to more effective details in the manner described below, and as detailed in Table 3:

- Subcase A:
  - Ungasketed Fitting Covers
    (except that the Access Hatches are bolted and gasketed, as required by API 650, Appendix C ([1]).
  - Uncontrolled Guidepole Fittings
    (i.e., no well gasket, no float with wiper, no pole wiper, and no pole sleeve)

- Uncontrolled Deck Legs
  (i.e., ungasketed, no socks)

- Subcase B:
  - Gasketed Fitting Covers
  - Gasketed Sliding Covers on Guidepole Fittings
  - Uncontrolled Deck Legs

- Subcase C:
  - Gasketed Fitting Covers
  - Improved Guidepole Fittings
    (i.e. incorporating some of the loss control construction details)
  - Uncontrolled Deck Legs

- Subcase D:
  - Gasketed Fitting Covers
  - Fully-Controlled Guidepole Fittings
  - Uncontrolled Deck Legs

- Subcase E:
  - Gasketed Fitting Covers
  - Fully-Controlled Guidepole Fittings
  - Gasketed Deck Legs

5.2 Calculated Results for EFRTs

Figures 20 and 21 illustrate the calculated results for Cases 1 and 2, where the total deck-fitting loss factor, F_f, is plotted against tank diameter, D, for ambient wind speeds of 0, 5, 10 and 15 mi/hr.

Figures 22 and 23 illustrate the calculated results for Case 1 and 2, respectively, at a wind speed of 10 mi/hr. Figure 22, which applies to an EFRT with a slotted guidepole, shows for a 100 ft. diameter tank that the total deck-fitting loss factor reduces from 3,760 lb-mole/yr for Case 1a to 106 lb-mole/yr for Case 1e, a reduction of 3,654 lb-mole/yr, or a reduction of over 97%. Figure 23, which applies to an EFRT with an unslotted guidepole, shows for a 100 ft. diameter tank that the total deck-fitting loss factor reduces from 2,517 lb-mole/yr for Case 2a to 91 lb-mole/yr for Case 2e, a reduction of 2,426 lb-mole/yr, or a reduction of over 96%.

5.3 Calculated Results for CFRTs

Figures 24 and 25 illustrate the calculated results for Cases 3 and 4, where the total deck-fitting loss factor, F_f, is plotted against tank diameter, D. Figure 24, which applies to a CFRT with a slotted guidepole, shows that for a 100 ft. diameter tank the total deck-fitting loss factor reduces from 117 lb-mole/yr for Case 3a to 51 lb-mole/yr for

Case 3e, a reduction of only 66 lb-mole/yr. In comparison, Figure 25, which applies to a CFRT with an unslotted guidepole, shows that for a 100 ft. diameter tank the total deck-fitting loss factor reduces from 105 lb-mole/yr for Case 4a to 57 lb-mole/yr for Case 4e, a reduction of only 48 lb-mole/yr.

5.4 Comparison of an EFRT to a CFRT

The reduction in total deck-fitting loss factor in converting an EFRT to a CFRT can be evaluated by comparing Case 1a with Case 3a for a slotted guidepole, and by comparing Case 2a with Case 4a for an unslotted guidepole. For a 100 ft. diameter EFRT with a slotted guidepole at a wind speed of 10 mi/hr, the total deck-fitting loss factor reduces from 3,761 lb-mole/yr for Case 1a to 117 lb-mole/yr for Case 3a. For a 100 ft. diameter EFRT with an unslotted guidepole at a windspeed of 10 mi/hr, the total deck-fitting loss factor reduces from 2,157 lb-mole/yr for Case 2a to 105 lb-mole/yr for Case 4a.

In comparison, as was discussed in Section 5.2 for the example of a 100 ft. diameter tank at a windspeed of 10 mi/hr, when effective loss control construction details are used on EFRT deck fittings, the total deck-fitting loss factor was reduced to 106 lb-mole/yr for Case 1e with a slotted guidepole and was reduced to 91 lb-mole/yr for Case 2e with an unslotted guidepole.

Thus, it is possible to achieve essentially the same total deck-fitting loss factor by either: (1) using effective loss control construction details on EFRT deck fittings; or (2) converting the EFRT to a CFRT by adding a self-supporting fixed roof. It is generally more cost-effective to add effective loss control construction details to EFRT deck fittings than to convert an EFRT to a CFRT.

One advantage, however, in converting an EFRT to a CFRT is that if it is necessary to later further reduce storage tank emissions, the fixed roof on the CFRT permits the collection of storage tank emissions so that they can be treated by an Emission Abatement System.

5.5 Improved Guidepole Fittings

Figures 26 and 27 illustrate the benefit that will occur in product conservation for both refined products and crude oil products by incorporating all of the loss control construction details on a previously uncontrolled slotted guidepole/sample well. Figure 26 shows, for example, that for a refined product with a vapor pressure of 6 psia and an ambient wind speed of 15 mi/hr, the annual product savings is about 10,000 gallons per year. Thus, by incorporating the loss control construction details in only this deck fitting, it is possible to both reduce atmospheric emissions and conserve a considerable quantity of product, the savings of which can be used to help defray the costs of incorporating the added loss control construction details.

Special construction details and installation procedures have been developed to retrofit slotted guidepole/sample wells with the improved loss control features when the tank is still in service. These procedures require enclosing the deck fitting and purging the enclosure with nitrogen during the retrofit installation. Some of the loss control features (e.g., sliding cover, pole wiper and pole sleeve) are of split-construction to permit their assembly around an existing slotted guidepole.

5.6 Improved Deck Legs

After reducing the evaporative loss from the guidepole fitting, the deck legs are typically next in importance since there are many deck legs on large diameter floating roofs. Loss reductions can be accomplished by retrofitting existing deck legs with boots, or by incorporating gaskets in the deck legs. Boots can typically be installed over deck legs while the tank is still in service, whereas it may be necessary to remove the tank from service to install gaskets on the deck legs.

6.0 CONCLUSIONS

- New Deck-Fitting Loss Factors Have Been Measured
  As a result of an API-sponsored test program [12, 13, 14, 15], deck-fitting loss factors have been measured for the different types of deck fittings and construction details used on EFRTs and CFRTs. These new deck-fitting loss factors have permitted an evaluation of alternative methods of significantly reducing the evaporative loss from certain deck fittings, such as slotted guidepole/sample wells.

- A Deck-Fitting Wind-Speed Correction Factor Has Been Developed
  As a result of another API-sponsored test program [8], a deck-fitting wind-speed correction factor has been developed that permits calculation of the deck-fitting evaporative loss at wind conditions typical of those on the floating-roof deck rather than at the ambient wind speed. This correction factor results in the deck-fitting loss factor being calculated at a wind speed that is 70% of the ambient wind speed at the tank site.

- The Evaporative Loss From Guidepole Fittings on EFRTs Can Be Better Controlled
  The largest source of standing storage loss is generally the deck-fitting loss for EFRTs equipped with rim-seal systems that include a rim-mounted secondary seal. Slotted or unslotted guidepole fittings which do not incorporate effective loss control features are typically the deck fitting with the highest evaporative loss contribution. Alternative effective loss control construction details have been identified and tested that can significantly reduce the evaporative loss from guidepole fittings.

- **<u>Equipping the Deck Fittings on an EFRT With Improved Loss Control Features is as Effective as Converting the EFRT to a CFRT</u>**
  When effective loss control features are incorporated in the deck fittings used on EFRTs, the total deck-fitting loss can be significantly reduced. As compared with the alternative of converting an EFRT to a CFRT, incorporating effective loss control construction details in the deck fittings of an EFRT is generally a more cost effective alternative.

- **<u>CFRTs Provide the Capability to Collect Emissions if a Zero Emission Storage Tank is Required</u>**
  If it is expected to later be necessary to further reduce further evaporative losses from the floating-roof tank, conversion of an EFRT to a CFRT permits the emissions to be collected for treatment by an emission abatement system. Currently, however, it is not typically required to collect floating roof tank emissions and further treat them, except for unusual products where there is a concern for personnel exposure to product vapors or odors, or when a Zero Emission Storage Tank (ZEST) is required by the tank owner.

7.0 REFERENCES

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NOMENCLATURE

SYMBOL	DESCRIPTION	UNITS
D	Tank diameter	ft
F_d	Total deck-seam loss factor	lb-mole/yr
F_f	Total deck-fitting loss factor	lb-mole/yr
F_r	Total rim-seal loss factor	lb-mole/yr
F_t	Total floating-roof loss factor	lb-mole/yr
K_c	Product factor	dimensionless
K_f	Deck-fitting loss factor	lb-mole/yr
K_{fa}	Zero-wind-speed deck-fitting loss factor	lb-mole/yr
K_{fb}	Wind-dependent deck-fitting loss factor	lb-mole/(mi/hr)^{m}yr
K_r	Rim-seal loss factor	lb-mole/ft yr
K_{ra}	Zero-wind-speed rim-seal loss factor	lb-mole/ft yr
K_{rb}	Wind-dependent rim-seal loss exponent	lb-mole/(mi/hr)^{n}yr
K_v	Deck-fitting wind-speed correction factor	dimensionless
L_s	Standing storage loss	lb/yr
L_t	Total loss	lb/yr
L_w	Withdrawal loss	lb/yr
m	Wind-dependent deck-fitting loss exponent	dimensionless
M_v	Product vapor molecular weight	lb/lb-mole
n	Wind-dependent rim-seal loss exponent	dimensionless
N_{fi}	Number of deck fittings of a particular type (i=1,2,...,k)	dimensionless
P	Product vapor pressure	psia
P^*	Vapor pressure function	dimensionless
P_a	Atmospheric pressure	psia
V	Ambient wind speed at the tank site	mi/hr

TABLE 1

Vapor Pressure Function, P*, as a Function of Product Vapor Pressure, P

Table is for atmospheric pressure, P_a, equal to 14.7 psia.

Vapor Pressure (psia)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	Vapor Pressure Function, P* (dimensionless)									
1.0	0.018	0.019	0.021	0.023	0.025	0.027	0.029	0.031	0.033	0.035
2.0	0.037	0.039	0.041	0.043	0.045	0.047	0.049	0.051	0.053	0.055
3.0	0.057	0.059	0.061	0.063	0.066	0.068	0.070	0.072	0.075	0.077
4.0	0.079	0.082	0.084	0.086	0.089	0.091	0.094	0.096	0.099	0.101
5.0	0.104	0.106	0.109	0.111	0.114	0.117	0.119	0.122	0.125	0.128
6.0	0.130	0.133	0.136	0.139	0.142	0.145	0.148	0.151	0.154	0.157
7.0	0.160	0.163	0.167	0.170	0.173	0.177	0.180	0.183	0.187	0.190
8.0	0.194	0.198	0.201	0.205	0.209	0.213	0.216	0.220	0.224	0.228
9.0	0.233	0.237	0.241	0.245	0.250	0.254	0.259	0.263	0.268	0.273
10.0	0.278	0.283	0.288	0.293	0.298	0.303	0.309	0.314	0.320	0.326
11.0	0.332	0.338	0.344	0.351	0.357	0.364	0.371	0.378	0.385	0.392
12.0	0.400	0.408	0.416	0.424	0.433	0.442	0.451	0.461	0.471	0.482

Note: From the first column, select the number which represents the integer portion of the vapor pressure. From the top row, select the number which represents the fractional portion the vapor pressure. The intersection of the row and column will give the vapor pressure function.

TABLE 2 - Deck Fitting Loss Factors (1)

Deck Fitting Type and Construction Details	Zero-Wind-Speed Loss Factor K_{fa} (lb-mole/yr)	Wind-Dependent Loss Factor K_{fb} (lb-mole/(mph)^m-yr)	Wind-Dependent Loss Exponent m (dimensionless)	Deck Fitting Loss Factor K_f (lb-mole/yr)			
				0 (mph)	5 (mph)	10 (mph)	15 (mph)
1. Access Hatches							
Unbolted cover, ungasketed	36	5.9	1.2	36.0	62.5	96.9	135.1
Unbolted cover, gasketed	31	5.2	1.3	31.0	57.5	96.3	141.5
Bolted cover, gasketed	1.6	0.0	0.0	1.6	1.6	1.6	1.6
2. Gauge-Float Wells							
Unbolted cover, ungasketed	14	5.4	1.1	14.0	35.4	59.9	85.7
Unbolted cover, gasketed	4.3	17	0.38	4.3	31.7	39.9	45.8
Bolted cover, gasketed	2.8	0.0	0.0	2.8	2.8	2.8	2.8
3. Gauge-Hatch/Sample Wells							
Weighted mechanical actuation, ungasketed	2.3	0.0	0.0	2.3	2.3	2.3	2.3
Weighted mechanical actaution, gasketed	0.47	0.021	0.97	0.5	0.5	0.6	0.7
4. Vacuum Breakers							
Weighted mechanical actuation, ungasketed	7.8	0.0065	4.0	7.8	8.8	23.4	86.8
Weighted mechanical actuation, gasketed	6.2	1.2	0.94	6.2	10.1	13.7	17.1
5. Deck Drains							
3-inch diameter, open	1.5	0.21	1.7	1.5	3.3	7.2	12.9
3-inch diameter, (10% open area)	1.8	0.14	1.1	1.8	2.4	3.0	3.7
6. Deck Legs							
Adjustable (double deck roofs and center area of pontoon roofs)							
Ungasketed, no sock	0.82	0.53	0.14	0.82	1.45	1.52	1.56
Gasketed, no sock	(2) 0.53	(2) 0.11	(2) 0.10	0.53	0.65	0.66	0.67
Ungasketed, with sock	(2) 0.49	(2) 0.20	(2) 0.10	0.49	0.72	0.74	0.75
Adjustable (pontoon area of pontoon roofs)							
Ungasketed, no sock	2.0	0.37	0.91	2.00	3.16	4.17	5.14
Gasketed, no sock	1.3	0.075	0.65	1.30	1.47	1.57	1.65
Ungasketed, with sock	1.2	0.14	0.65	1.20	1.52	1.70	1.85
Fixed	0.0	0.0	0.0	0.00	0.00	0.00	0.00
7. Rim Vents							
Weighted mechanical actuation, ungasketed	0.68	1.8	1.0	0.7	7.0	13.3	19.6
Weighted mechanical actuation, gasketed	0.71	0.10	1.0	0.7	1.1	1.4	1.8
8. Unslotted Guidepole Wells							
Well Gasket / Float with Wiper / Pole Wiper / Pole Sleeve							
N N N N	31	150	1.4	31.0	897.5	2317.8	4065.2
Y N N N	25	13	2.2	25.0	229.6	965.1	2318.8
N N N Y	25	2.2	2.1	25.0	55.5	156.0	331.8
Y N N Y	8.6	12	0.81	8.6	41.7	66.6	89.2
Y N Y N	14	3.7	0.78	14.0	23.8	30.9	37.2
9. Slotted Guidepole/Sample Wells							
N N N N	46	190	1.5	46.0	1290.1	3564.8	6510.5
Y N N N	41	380	1.2	41.0	1749.7	3966.6	6426.7
N Y N N	36	39	2.1	36.0	577.5	2357.5	5475.5
Y Y N N	26	33	1.9	26.0	382.7	1357.1	2901.9
Y N Y N	41	48	1.4	41.0	318.3	772.8	1331.9
Y N N Y	16	21	1.8	16.0	216.2	713.3	1462.6
Y N Y Y	(3) 8.3	(3) 2.7	(3) 2.2	8.3	101.4	436.2	1052.5
Y Y Y N	24	4.7	1.9	24.0	74.8	213.6	433.6
Y Y Y Y	9.1	15	0.46	9.1	35.8	45.8	53.3

Notes: (1). Except where noted, all deck-fitting loss factors are from draft API MPMS, Chapter 19.2 [6].
(2). These loss factors were projected from the test results on pontoon area deck legs.
(3). From Reference [15].

TABLE 3 - Summary of Deck Fitting Types and Construction Details for Cases 1 Through 4

Deck Fitting Type and Construction Details	Case 1 EFRT with Slotted Guidepole					Case 2 EFRT with Unslotted Guidepole					Case 3 CFRT with Slotted Guidepole					Case 4 CFRT with Unslotted Guidepole				
	1a	1b	1c	1d	1e	2a	2b	2c	2d	2e	3a	3b	3c	3d	3e	4a	4b	4c	4d	4e
1. Access Hatches																				
Unbolted cover, ungasketed																				
Unbolted cover, gasketed																				
Bolted cover, gasketed	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2. Gauge-Float Wells																				
Unbolted cover, ungasketed	X					X					X					X				
Unbolted cover, gasketed																				
Bolted cover, gasketed		X	X	X	X		X	X	X	X		X	X	X	X		X	X	X	X
3. Gauge-Hatch/Sample Wells																				
Weighted mechanical actuation, ungasketed						X										X				
Weighted mechanical actaution, gasketed							X	X	X	X							X	X	X	X
4. Vacuum Breakers																				
Weighted mechanical actuation, ungasketed	X					X					X					X				
Weighted mechanical actuation, gasketed		X	X	X	X		X	X	X	X		X	X	X	X		X	X	X	X
5. Deck Drains																				
3-inch diameter, open																				
3-inch diameter, (10% open area)	X	X	X	X	X	X	X	X	X	X										
6. Deck Legs																				
Adjustable (double deck roofs and center area of pontoon roofs)																				
Ungasketed, no sock	X	X	X	X		X	X	X	X		X	X	X	X		X	X	X	X	
Gasketed, no sock					X					X					X					X
Ungasketed, with sock																				
Adjustable (pontoon area of pontoon roofs)																				
Ungasketed, no sock	X	X	X	X		X	X	X	X		X	X	X	X		X	X	X	X	
Gasketed, no sock					X					X					X					X
Ungasketed, with sock																				
Fixed																				
7. Rim Vents																				
Weighted mechanical actuation, ungasketed	X					X					X					X				
Weighted mechanical actuation, gasketed		X	X	X	X		X	X	X	X		X	X	X	X		X	X	X	X
8. Unslotted Guidepole Wells																				
Well Gasket / Float with Wiper / Pole Wiper / Pole Sleeve																				
N N N N						X										X				
Y N N N							X										X			
N N N Y																				
Y N N Y								X										X		
Y N Y N									X	X									X	X
9. Slotted Guidepole/Sample Wells																				
N N N N	X										X									
Y N N N		X										X								
N Y N N																				
Y Y N N																				
Y N Y N																				
Y N N Y																				
Y N Y Y																				
Y Y Y N			X										X							
Y Y Y Y				X	X									X	X					

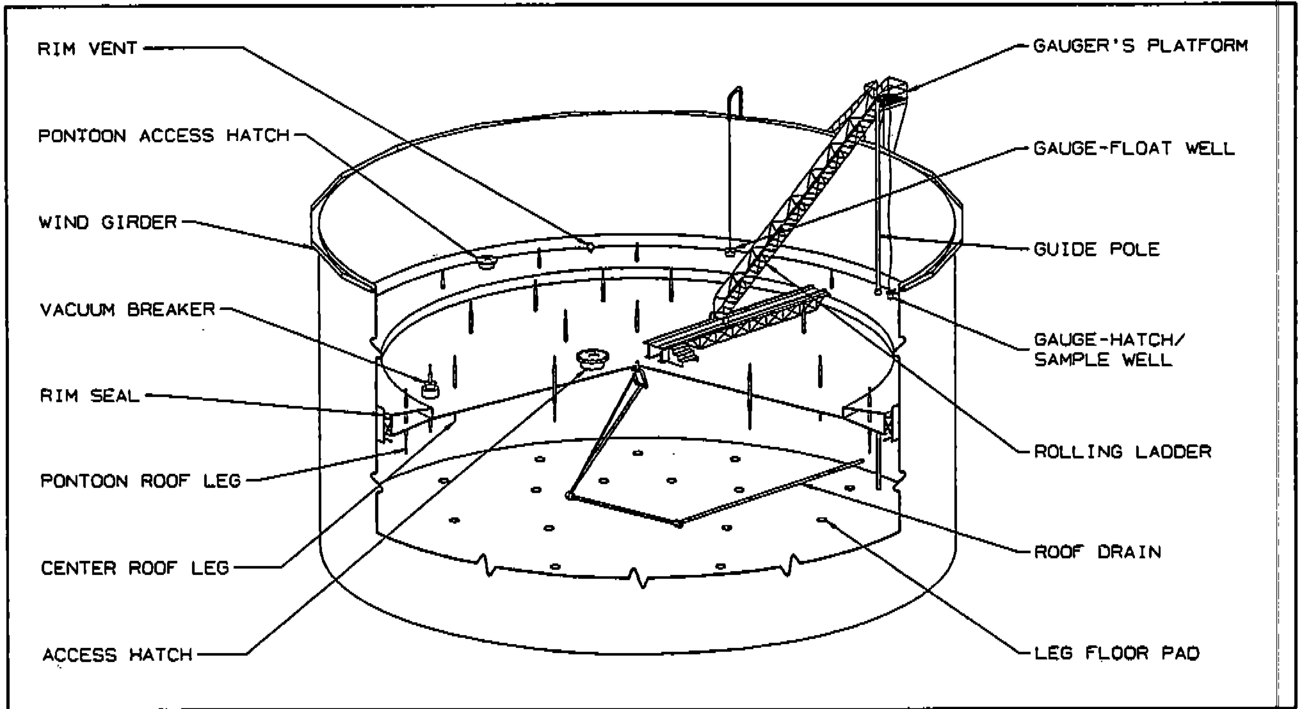


FIGURE 1 - Typical External Floating-Roof Tank (EFRT) With a Pontoon Floating Roof

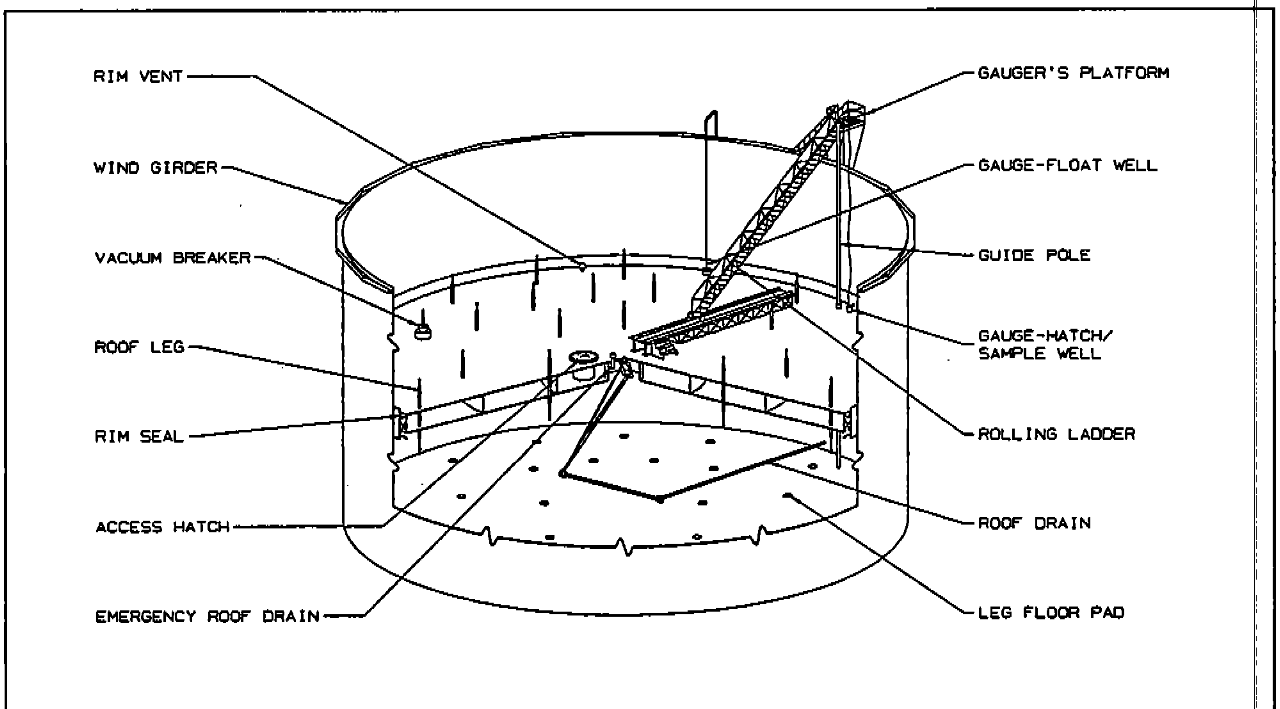


FIGURE 2 - Typical External Floating-Roof Tank (EFRT) With a Double-Deck Floating Roof

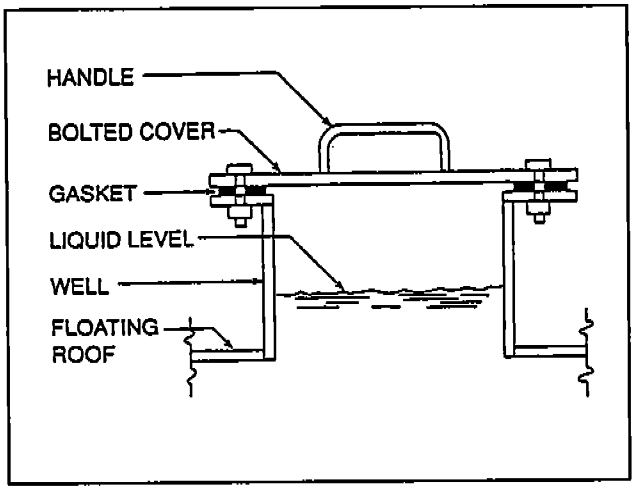


FIGURE 3 - Access Hatch

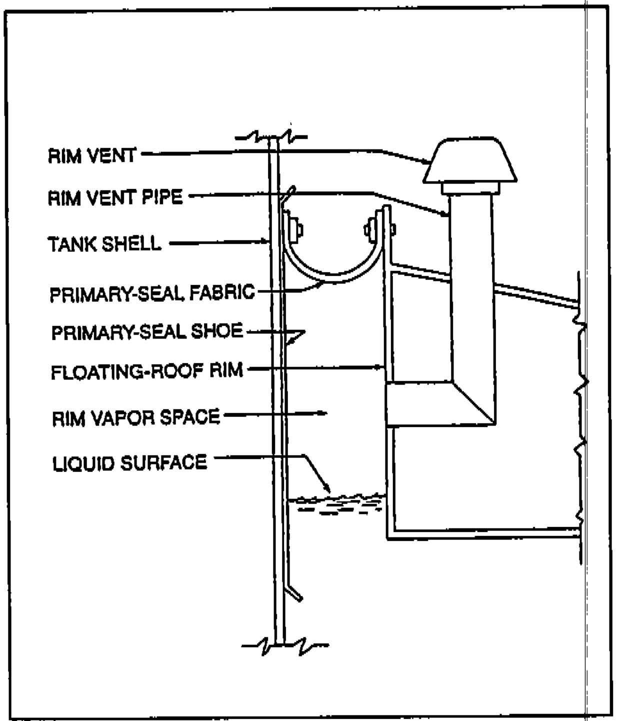


FIGURE 6 - Rim Vent

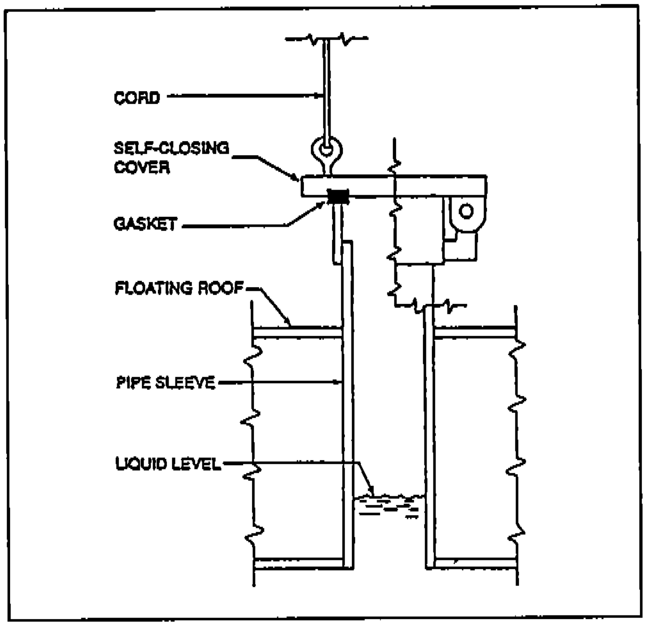


FIGURE 4 - Gauge-Hatch/Sample Well

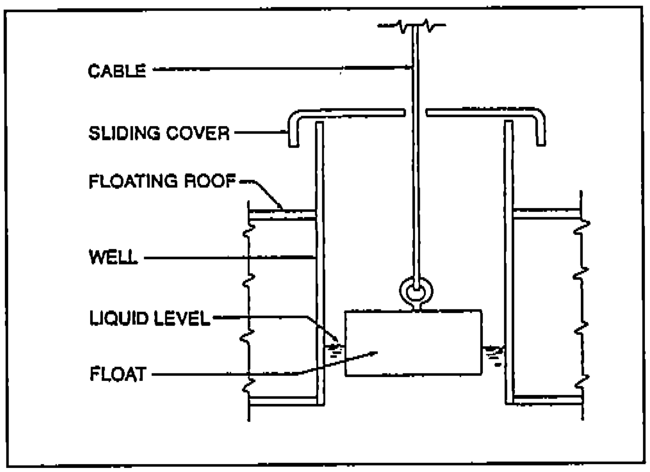


FIGURE 5 - Gauge-Float Well

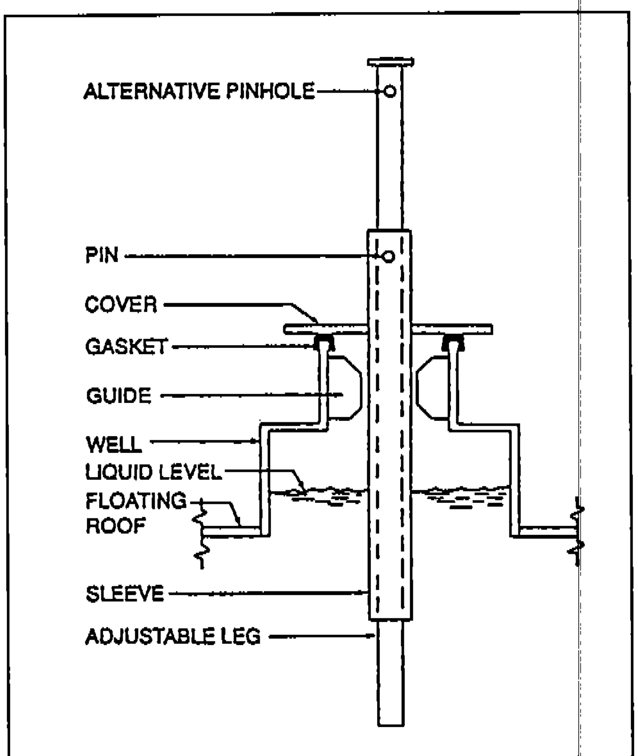


FIGURE 7 - Vacuum Breaker

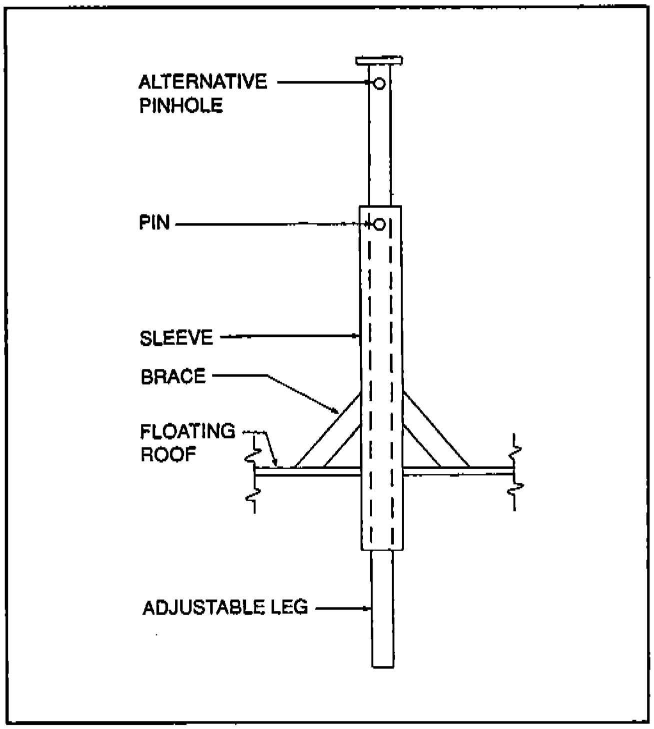


FIGURE 8 - Deck Leg

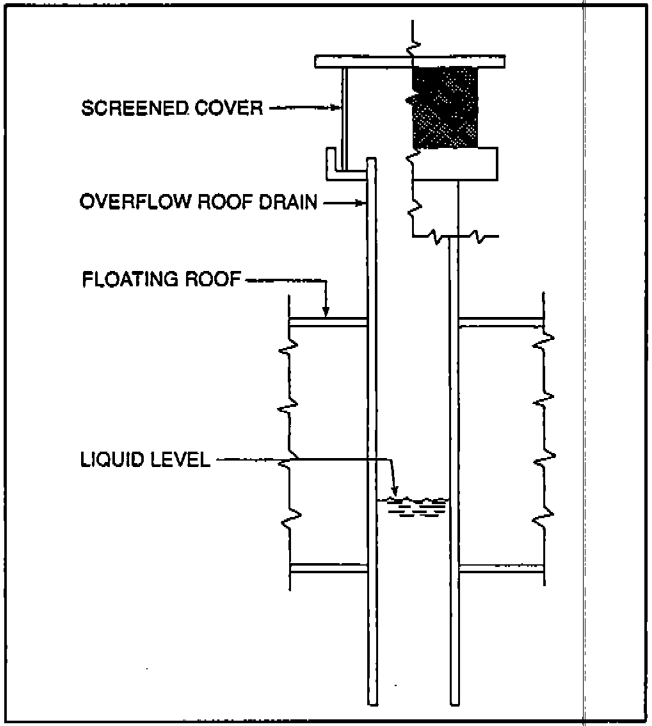


FIGURE 9 - Overflow Deck Drain

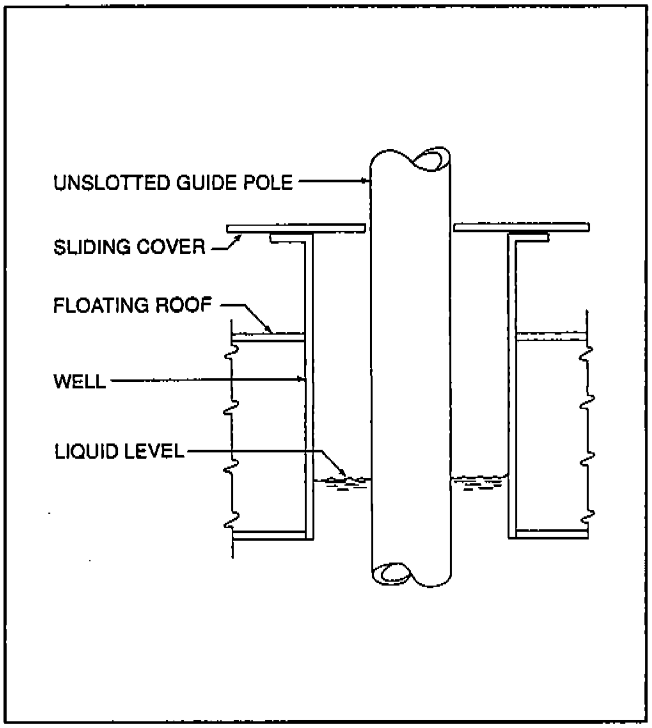


FIGURE 10 - Unslotted Guidepole Well

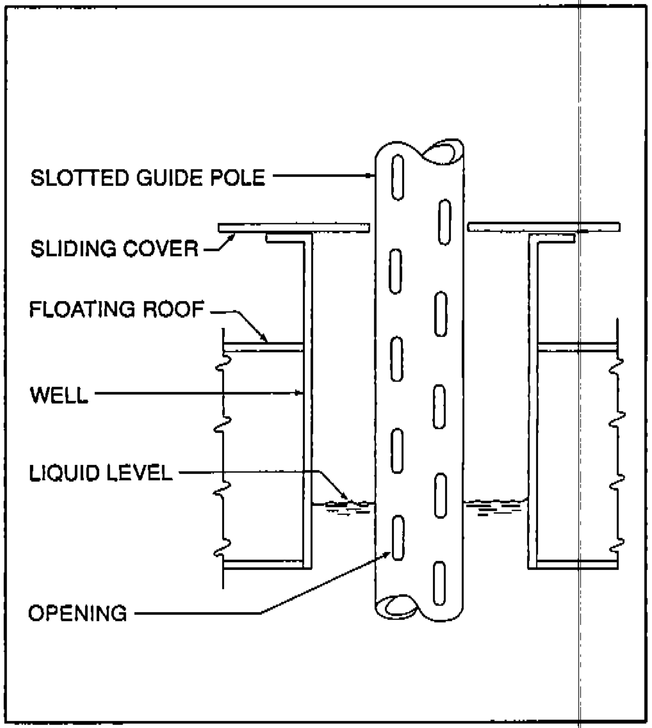


FIGURE 11 - Slotted Guidepole/Sample Well

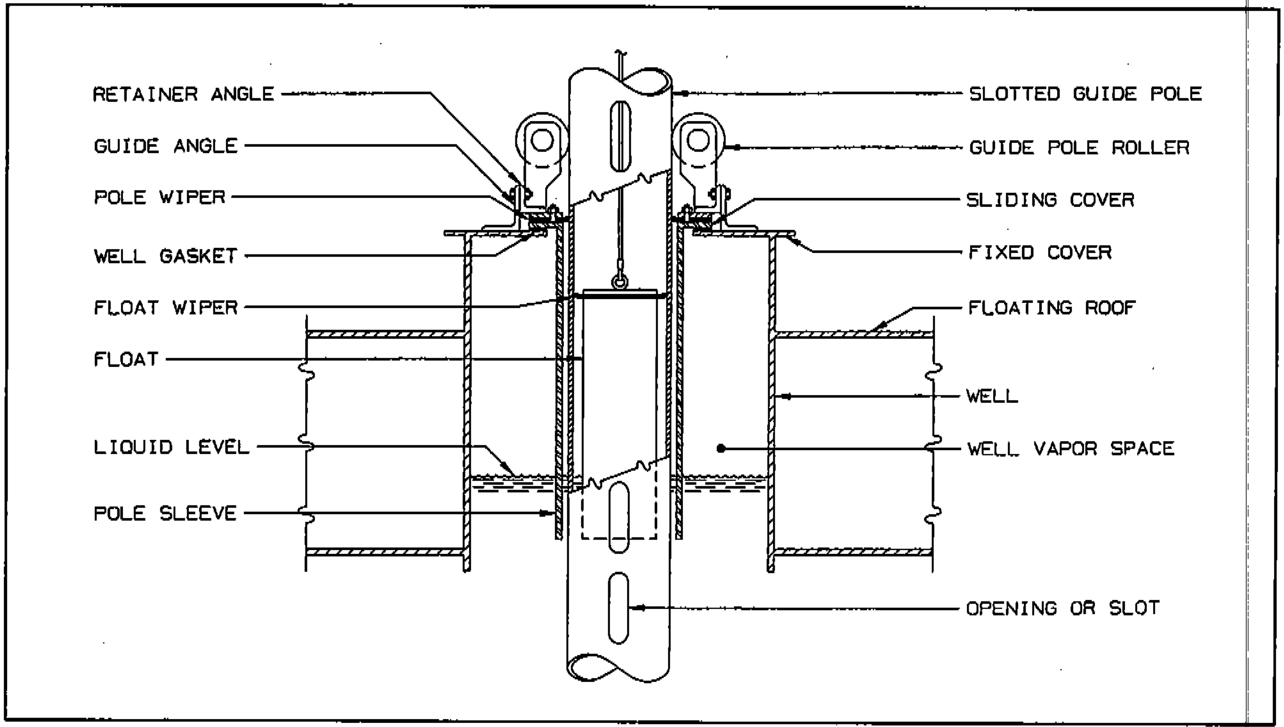


FIGURE 12 - Slotted Guidepole/Sample Well with Evaporative Loss Control Construction Details

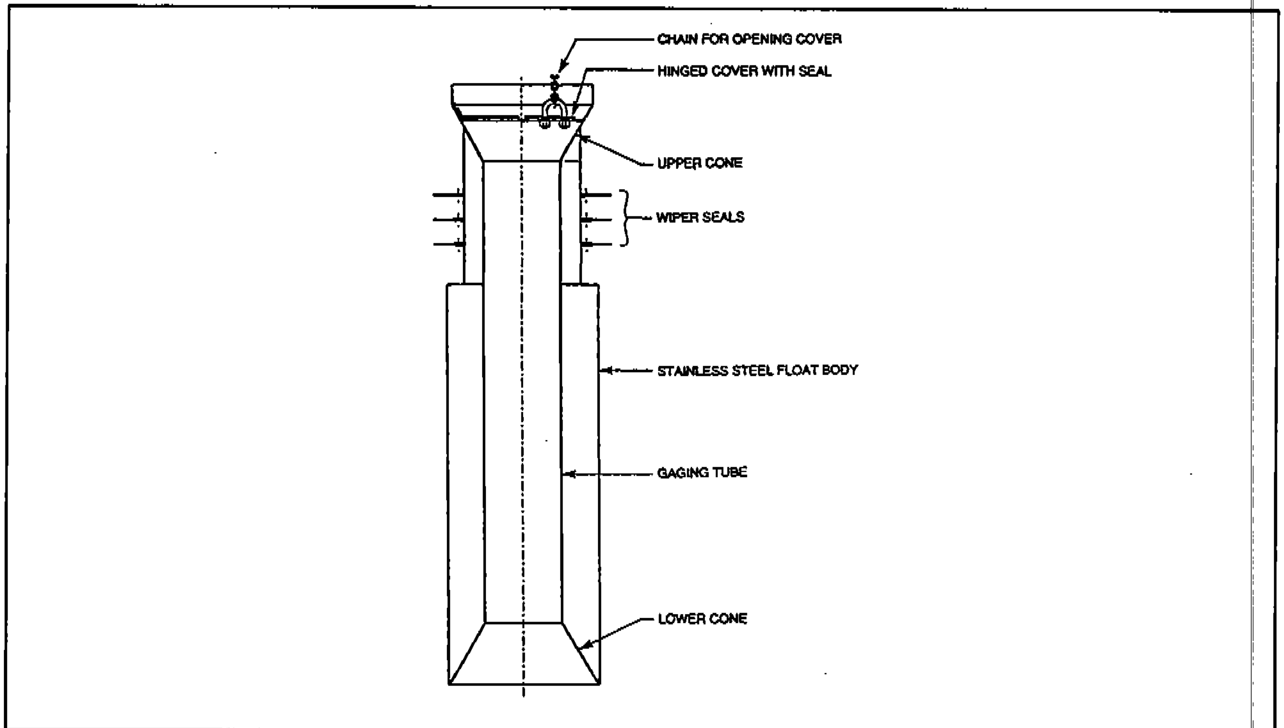


FIGURE 13 - Gauge/Sample Guidepole Float

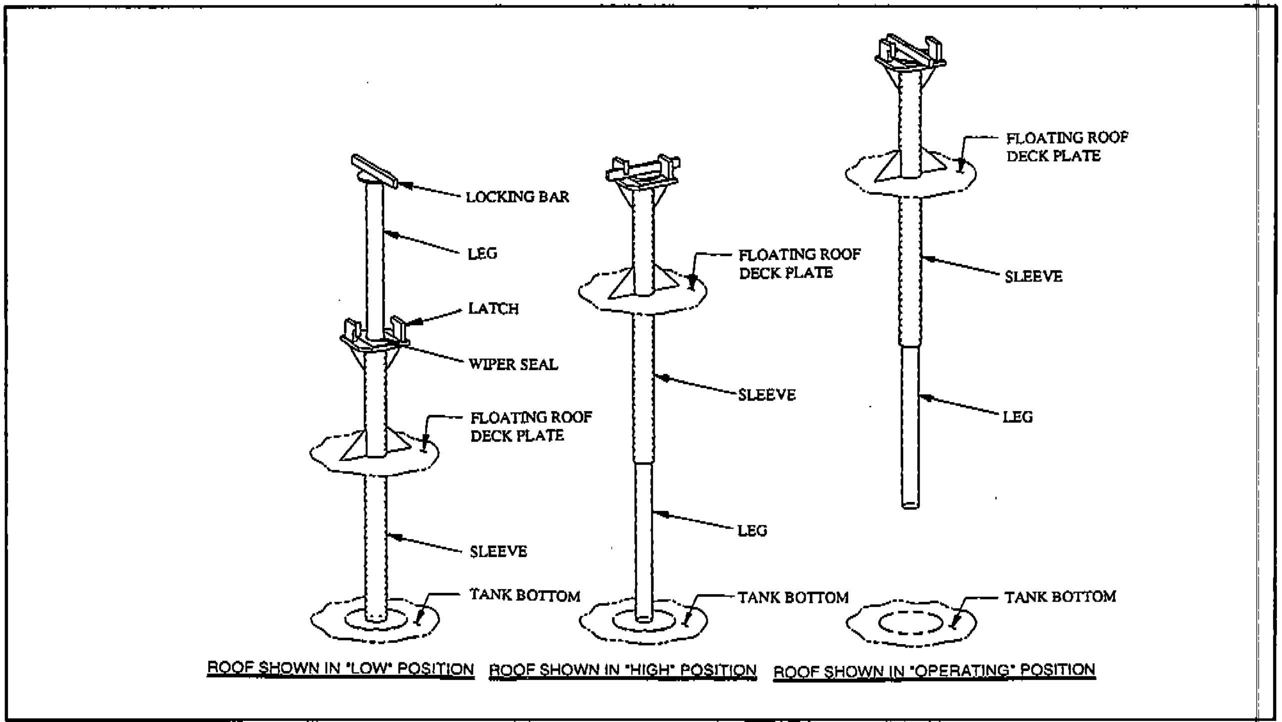


FIGURE 14 - Adjustable Gasketed Deck Leg for Pontoon or Double-Deck Floating Roofs

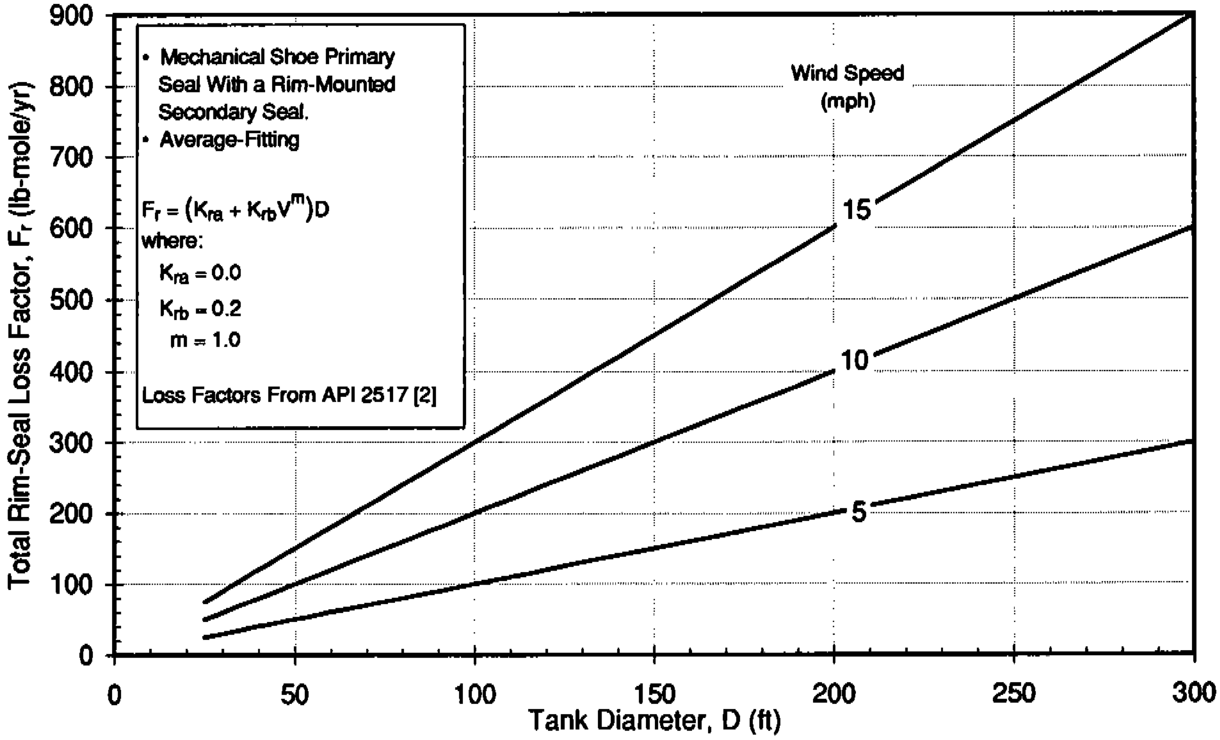


FIGURE 15- Total Rim-Seal Loss Factor for an EFRT With an Average-Fitting Mechanical-Shoe Primary Seal and a Rim-Mounted Secondary Seal

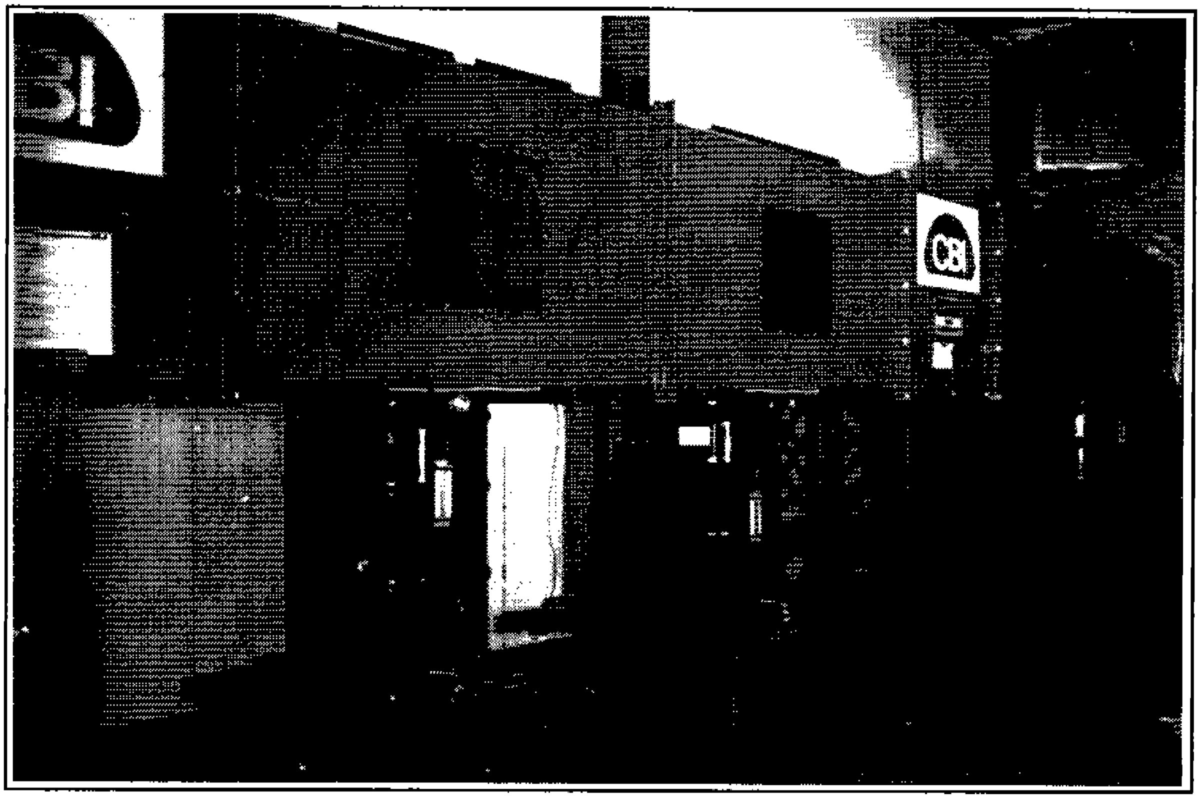


FIGURE 16 - Photograph of the Wind Tunnel Test Facility

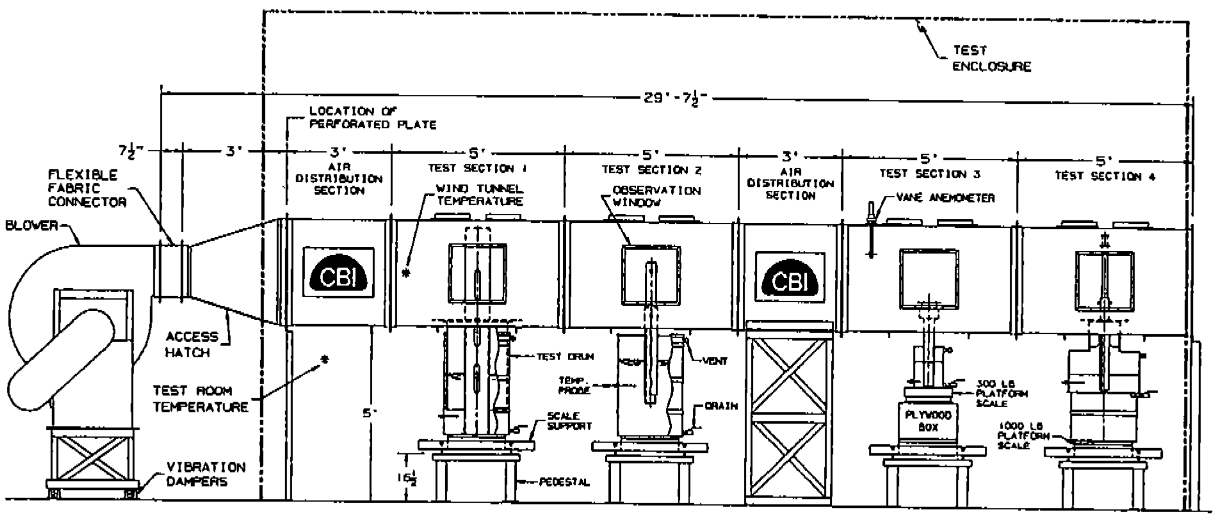


FIGURE 17 - Schematic of the Wind Tunnel Test Facility

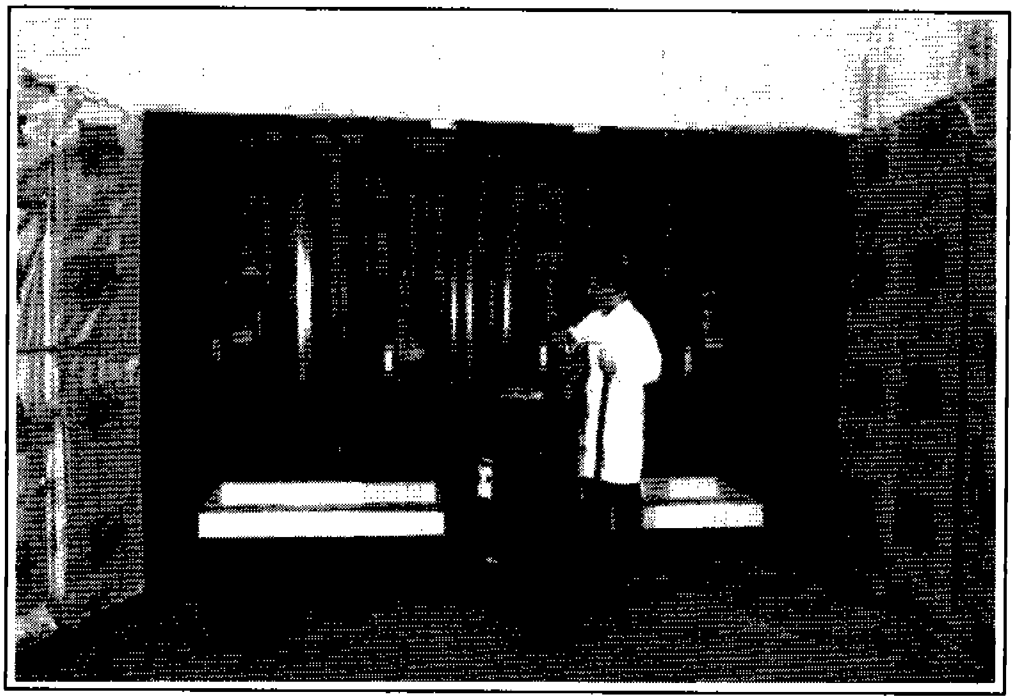


FIGURE 18 - Photograph of the Zero Wind Test Facility

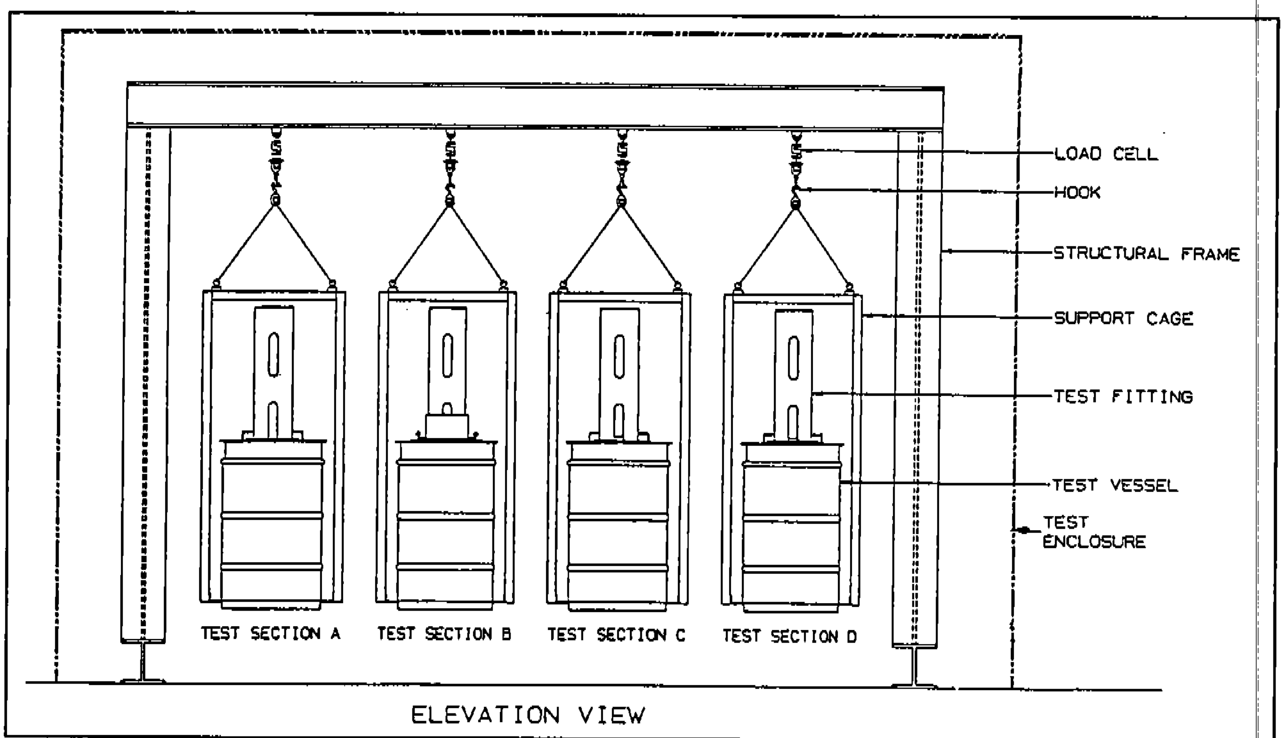
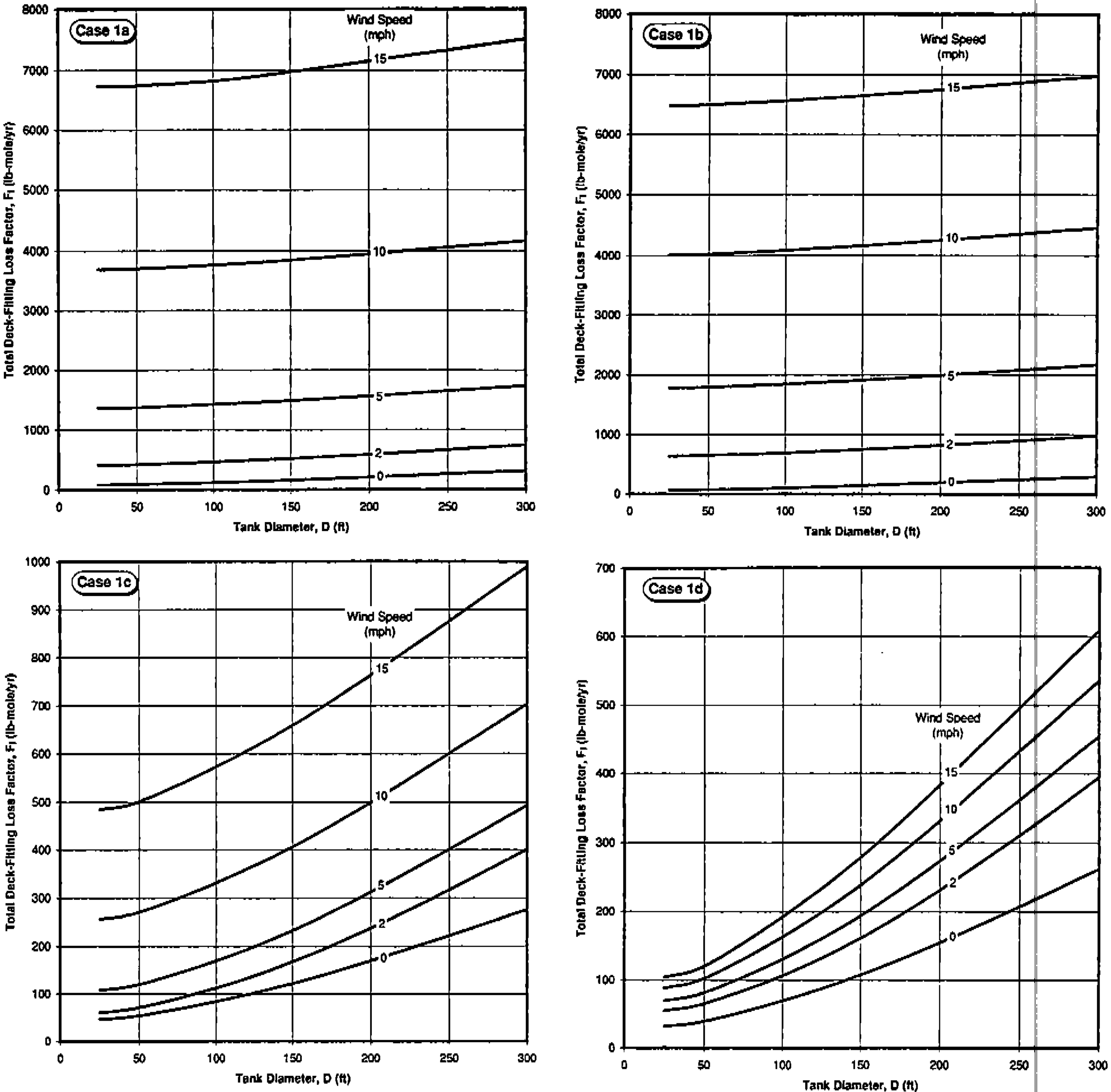


FIGURE 19 - Schematic of the Zero Wind Test Facility



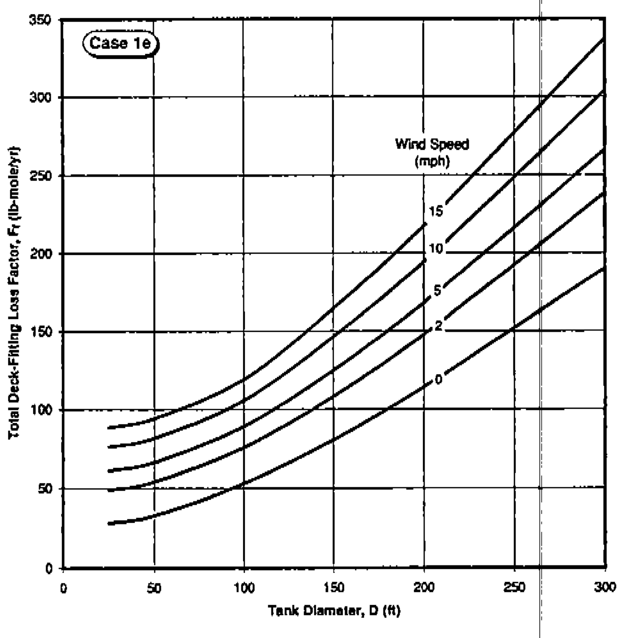
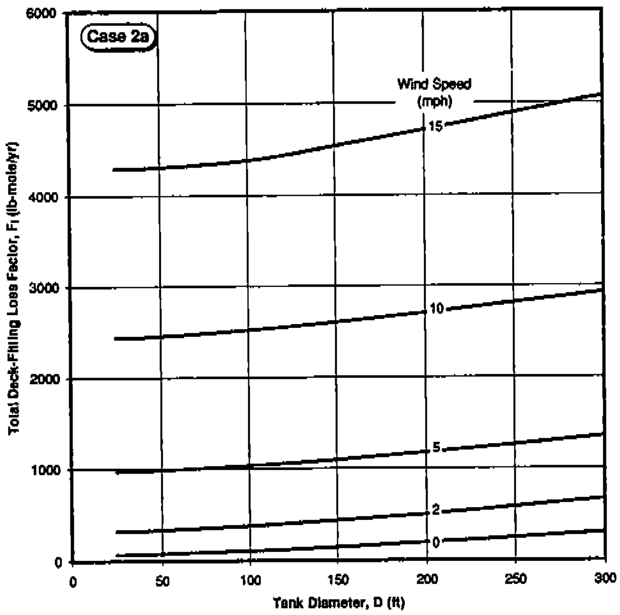
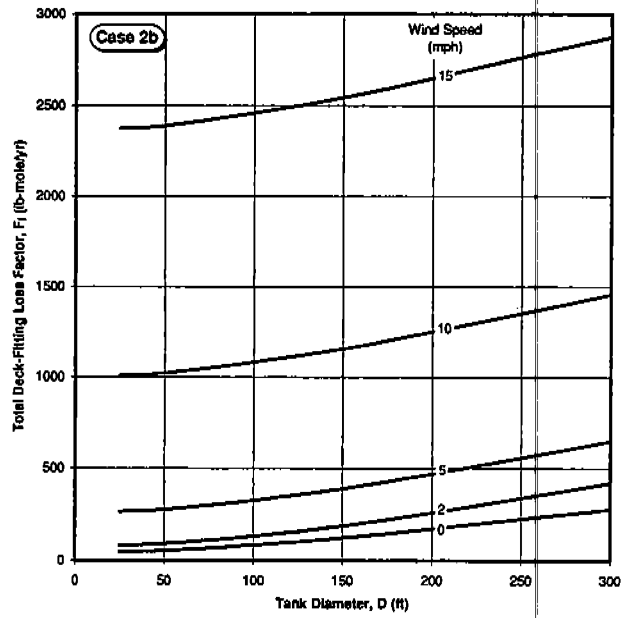
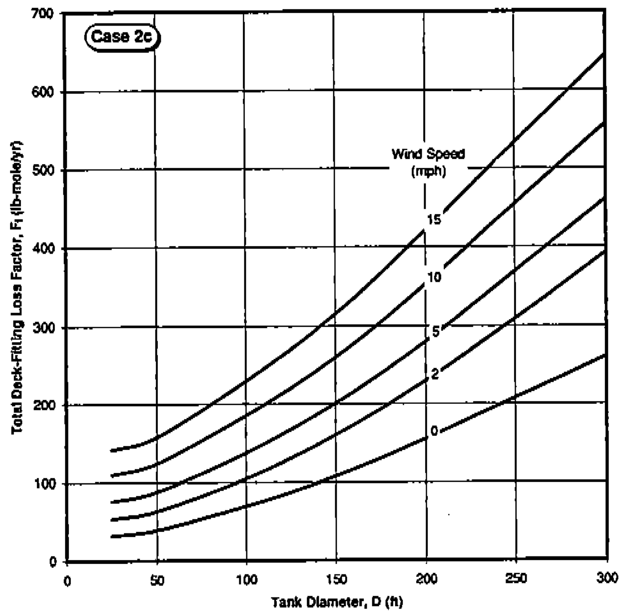


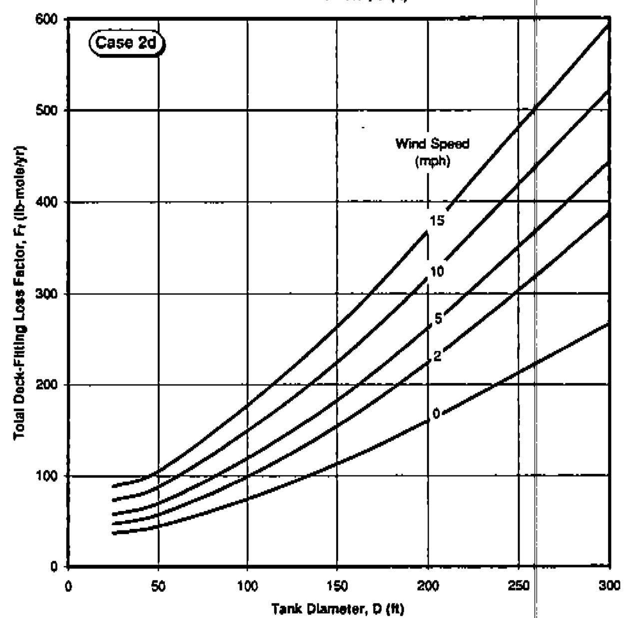
FIGURE 20

Total Deck-Fitting Loss Factor of an EFRT With a Pontoon Floating Roof for Case 1









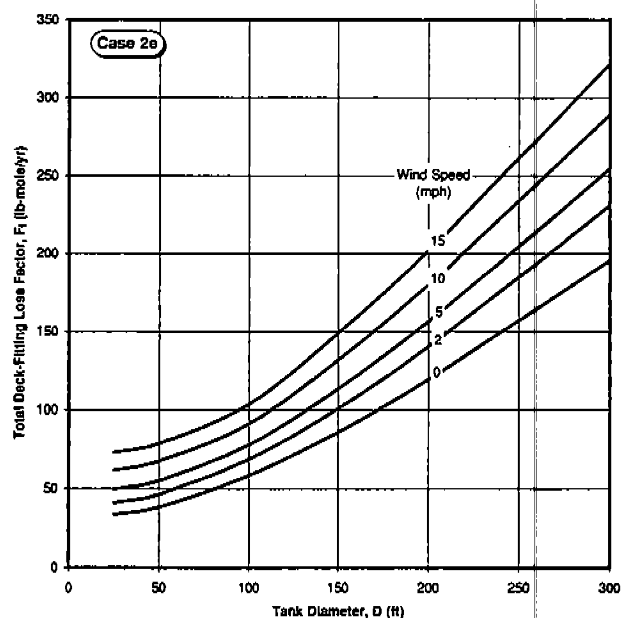


FIGURE 21
Total Deck-Fitting Loss Factor of an EFRT With a Pontoon Floating Roof for Case 2

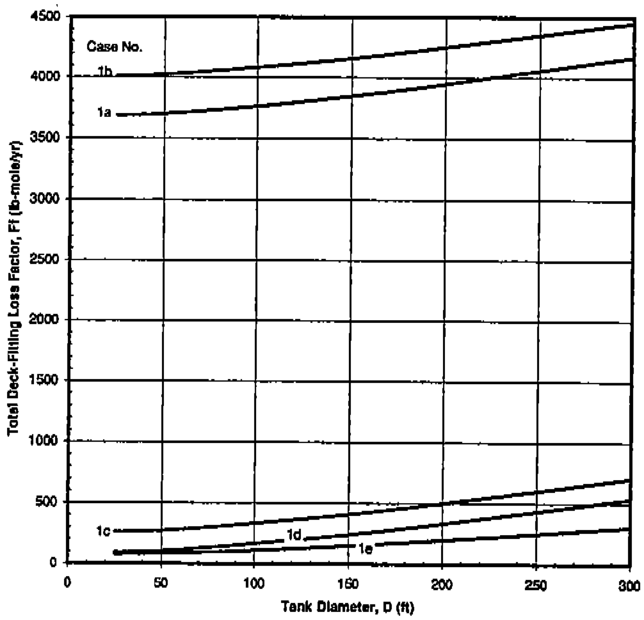


FIGURE 22
Total Deck-Fitting Loss Factor of an EFRT With a Pontoon Floating Roof at a Wind Speed of 10 mi/hr for Case 1

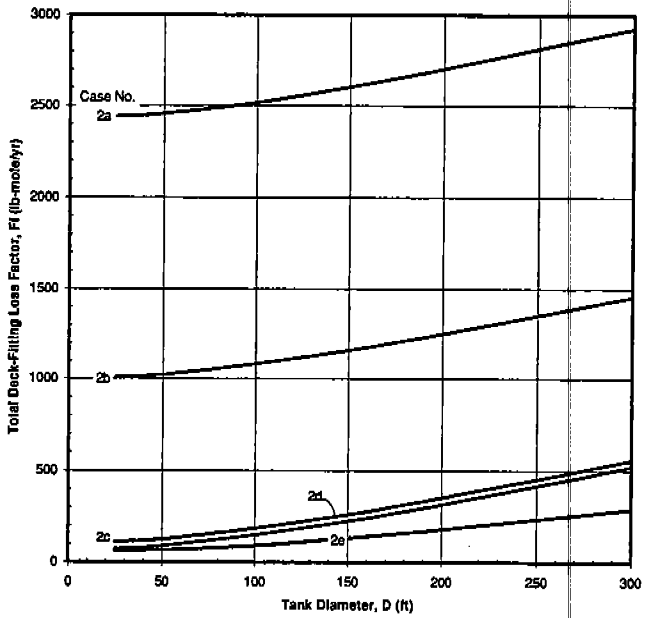


FIGURE 23
Total Deck-Fitting Loss Factor of an EFRT With a Pontoon Floating Roof at a Wind Speed of 10 mi/hr for Case 2

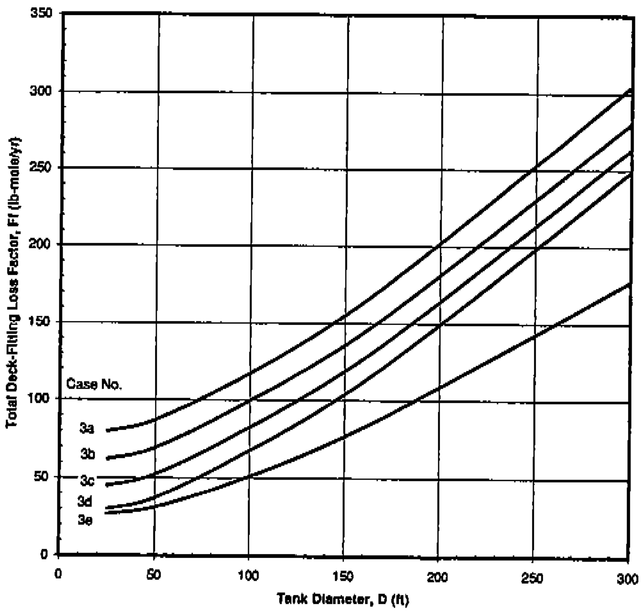


FIGURE 24
Total Deck-Fitting Loss Factor of a CFRT With a Pontoon Floating Roof for Case 4

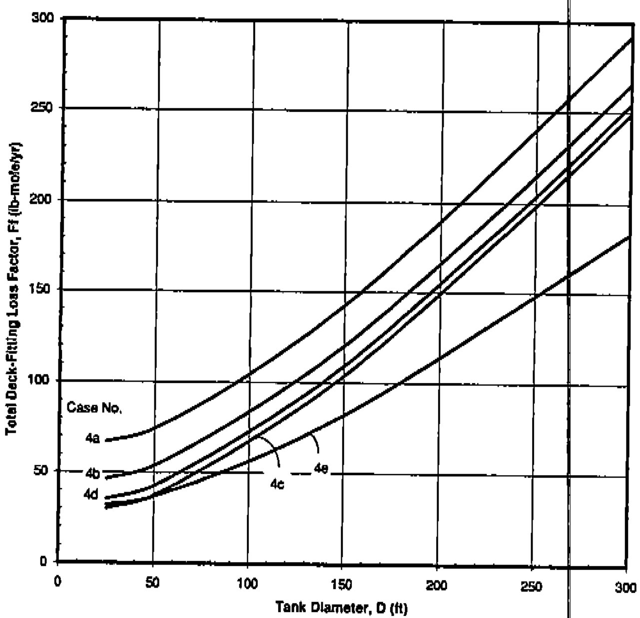


FIGURE 25
Total Deck-Fitting Loss Factor of a CFRT With a Pontoon Floating Roof for Case 3

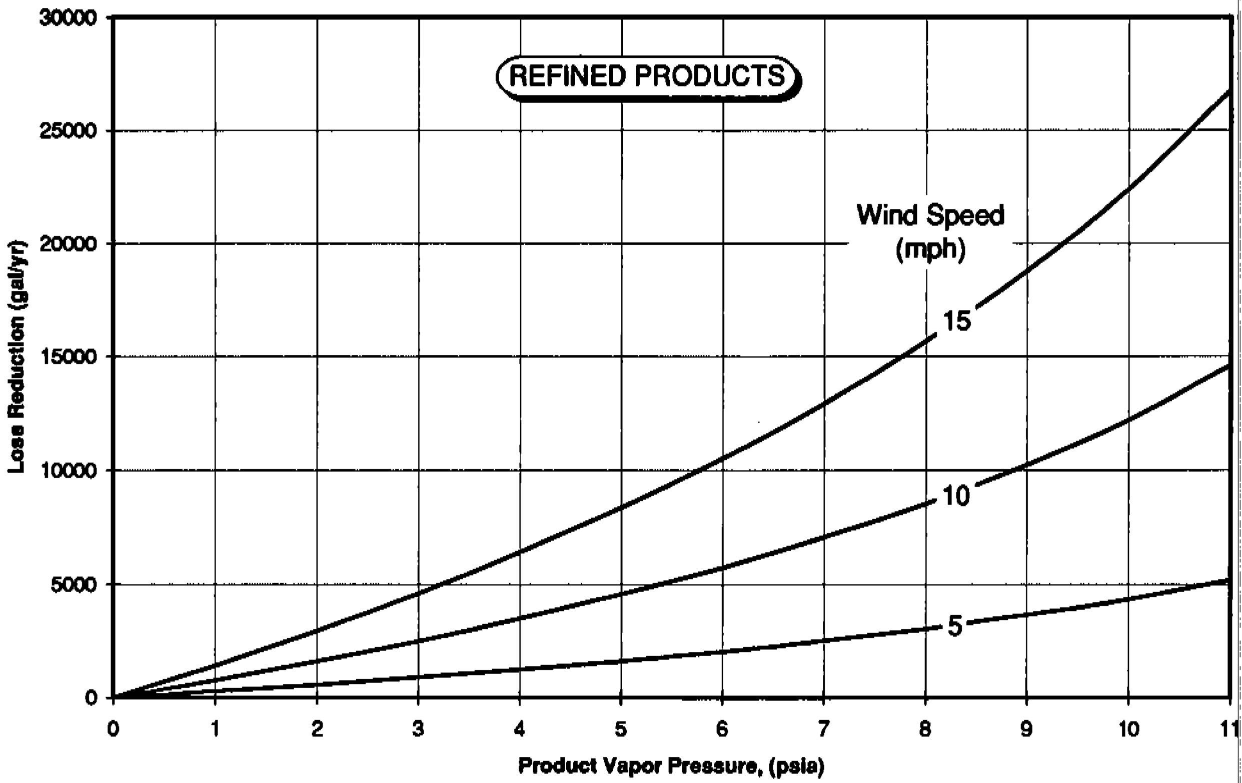


FIGURE 26 - Loss Reduction of a Slotted Guidepole Fitting for Refined Products

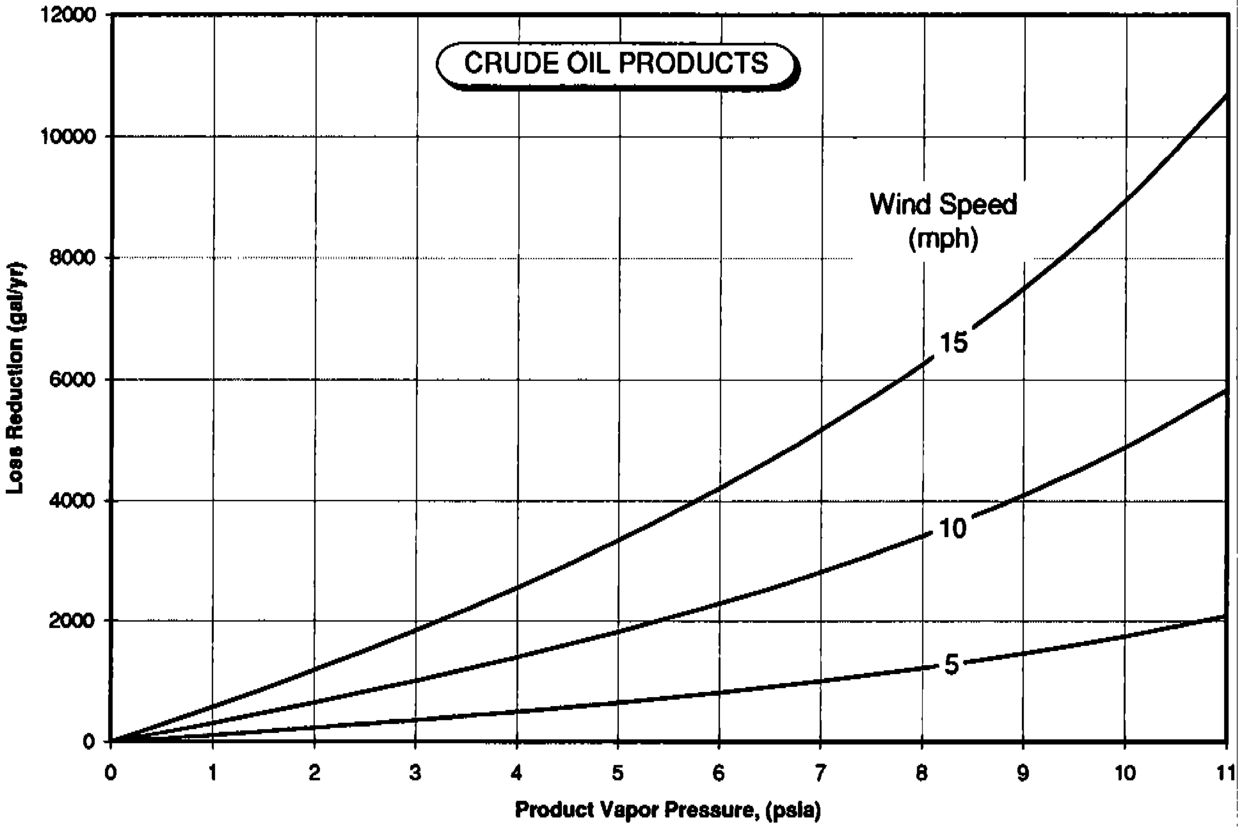


FIGURE 27 - Loss Reduction of a Slotted Guidepole Fitting for Crude Oil Products