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Estimating Air Toxics Emissions From Organic Liquid Storage Tanks

By
Patrick Murphy
Midwest Research Institute
Cary, North Carolina
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EPA Project Officer: Anne A. Pope

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office Of Air And Radiation
Office Of Air Quality Planning And Standards
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1.0 PURPOSE OF DOCUMENT

The U. S. Environmental Protection Agency and State and local air pollution control agencies are becoming increasingly aware of the presence of substances in the ambient air that may be toxic at certain concentrations. This awareness has led to an attempt to categorize air toxics emissions by sources, such as storage tanks.

To assist groups in inventorying air emissions of potentially toxic substances, EPA is preparing a series of documents that compiles available information on sources and emissions of these substances. This document deals with methods to estimate air toxics emissions from organic liquid storage tanks. Its intended audience includes Federal, State, and local air pollution agency personnel and others who are interested in making estimates of air toxics emissions from storage tanks.

This document informs the reader how to (1) characterize storage tanks, (2) select the appropriate storage tank loss equations and parameters for estimating emissions, (3) calculate vapor pressures, mole fractions, and molecular weights of mixtures, and (4) estimate emissions of individual air toxics. The emphasis of this document is on presenting equations for estimating air toxics emissions from storage tanks and demonstrating through examples how to use the equations.

The reader is cautioned against using the emission estimates as an exact assessment from any particular source because of the limitations of the estimating methods and the general lack of specific source information. If precise knowledge of emission levels is desired, the user is advised to measure emissions of air toxics from organic liquid storage tanks.

The storage tank emission estimating equations are based on equations presented in AP-42, and the user is advised to consult AP-42 for additional details regarding the equations.[3] This document expands information presented in AP-42 to include methodology for estimating emissions from mixtures stored in organic liquid storage tanks and revises the methodology for estimating emissions from external floating roof tanks. The revised external floating roof tank methodology includes procedures recently developed by the American Petroleum Institute.[17]

2.0 OVERVIEW OF DOCUMENT CONTENTS

This section provides an overview of the contents of this document. It briefly outlines the nature of the material presented in the remaining sections of this report.

Section 3 provides brief descriptions of different types of tanks and control devices. The sources of emissions that occur from each type of storage tank are also described.

Section 4 presents storage tank source category descriptions. Storage tanks have been divided into usage source categories in order to present common characteristics that are significant when estimating emissions. Some suggestions of how to locate storage tanks are presented in this section.

Section 5 presents descriptions of the methods recommended to make estimates of air toxic emissions from storage tanks. The emission estimating equations are presented along with explanations of their appropriate use. The selection of parameters and calculation of properties are explained in this section.

Section 6 presents the references used in this document.

Appendix A presents the physical constants of organic compounds commonly stored in tanks and tables and figures of other data required to use the equations. Appendix B presents four example calculations. The examples are intended to cover a wide range of scenarios and are very explicit. Proper use of the equations and typical assumptions are included in the examples.

3.0 STORAGE TANK BACKGROUND INFORMATION

This section presents descriptions of the five basic designs of organic liquid storage vessels: fixed roof, external floating roof, internal floating roof, variable vapor space, and pressure (low and high). Also, the types of emissions from these tanks are discussed.

3.1 FIXED ROOF TANKS

A typical fixed roof tank is shown in Figure 1. This type of tank consists of a cylindrical steel shell with a permanently affixed roof, which may vary in design from cone- or dome-shaped to flat.

The design of fixed roof tanks requires an opening vent to the atmosphere to allow for displaced air and vapors during filling, withdrawal, and expansion due to warming. Opening vents are commonly equipped with pressure/vacuum devices that allow the vessel to operate at a slight internal pressure or vacuum to prevent the release of vapors during very small changes in temperature, pressure, or liquid level. Of current tank designs, the fixed roof tank is the least expensive to construct and is generally considered to be the minimum acceptable equipment for storage of organic liquids.

Two significant types of emissions from fixed roof tanks are breathing loss and working loss. Breathing loss is the expulsion of vapor from a tank through vapor expansion and contraction, which result from changes in temperature and barometric pressure. During vapor contraction, air is drawn into the tank and becomes saturated with organic vapor. Upon subsequent expansion of the vapor, the saturated vapor is expelled from the tank. This loss occurs without any loading or withdrawal of liquid from the tank. For insulated tanks, no factors exist currently to estimated breathing losses.

The combined loss from filling and emptying the tank is called working loss. Filling loss occurs when, with an increase of the liquid level in the tank, the pressure inside the tank exceeds the relief pressure and vapors are expelled. Emptying loss occurs when air, drawn into the tank during liquid removal and saturated with organic vapor, is

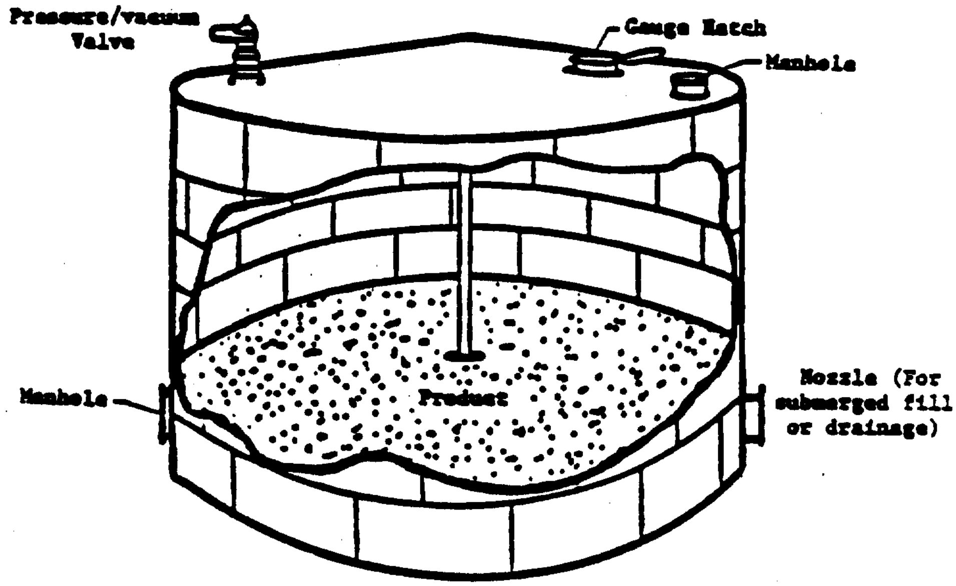
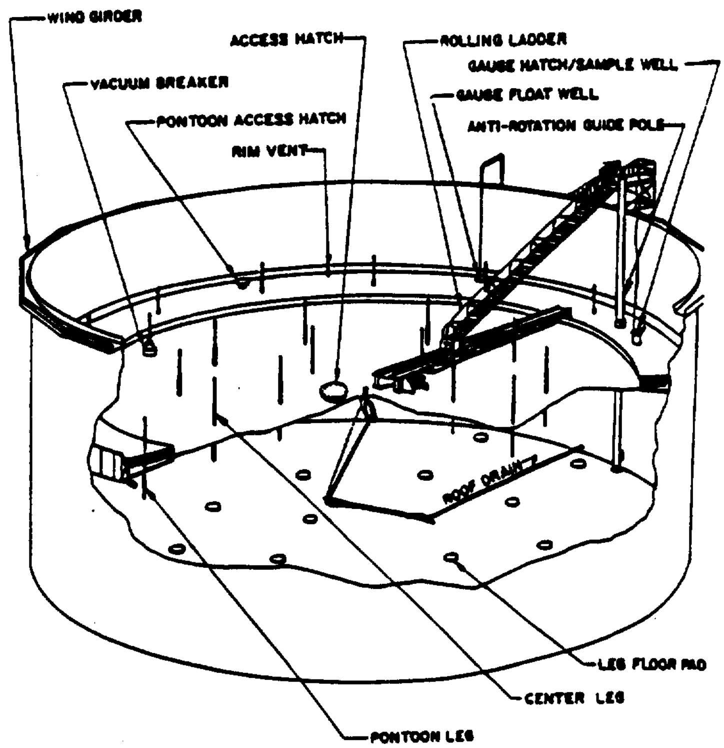


Figure 1. Typical fixed roof storage tank.

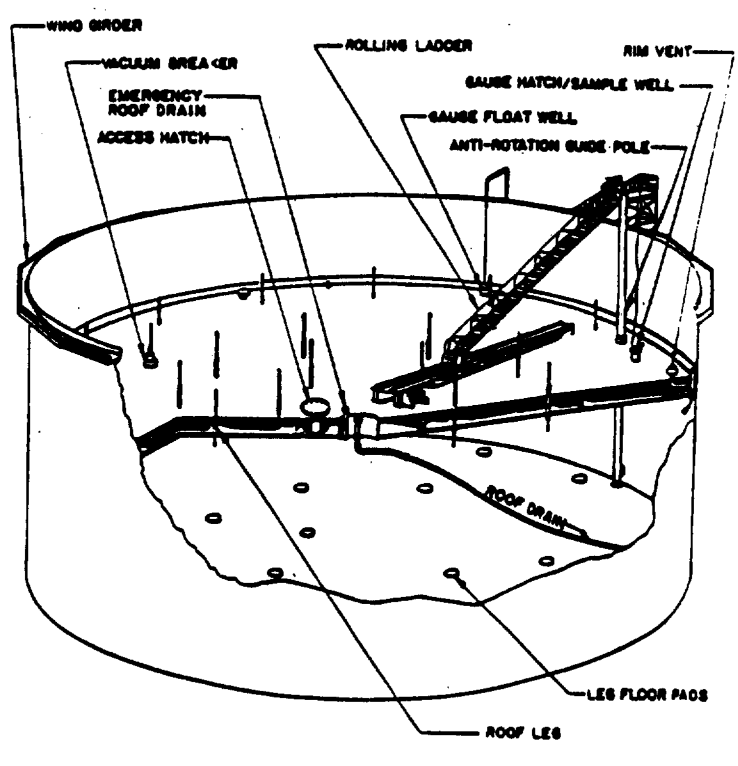
expelled as liquid is subsequently pumped into the tank, thus exceeding the capacity of the vapor space. Fixed roof emissions vary as a function of vessel capacity, vapor pressure of the stored liquid, utilization rate of the vessel, and atmospheric conditions at the tank location. Emissions from fixed roof tanks can be reduced by constructing internal floating roofs or by using add-on control devices such as vapor recovery or thermal oxidation.

3.2 EXTERNAL FLOATING ROOF TANKS

External floating roof tanks are cylindrical vessels that have a roof that floats on the surface of the liquid being stored. The basic components of the tank include: (1) a cylindrical shell, (2) a floating roof, (3) an annular rim seal attached to the perimeter of the floating roof, and (4) roof fittings that penetrate the floating roof and serve operational functions. The purpose of the floating roof and the seal (or seal system) is to reduce the evaporative loss of the stored liquid. Floating roofs are currently constructed of welded steel plates. The present trend in floating roof construction is toward two types of roofs: pontoon and double deck. Figure 2 shows typical external floating roof tanks of both types. The liquid surface is completely covered by the floating roof except at the small annular space between the roof and the tank wall. A seal (or seal system) attached to the roof contacts the tank wall (with small gaps, in some cases) and covers the annular space. The seal slides against the tank wall as the roof is raised or lowered. Floating roofs may have primary and secondary seals. Three types of primary seals are generally used--vapor mounted, liquid mounted, and mechanical shoe. Secondary seals are usually vapor mounted but may be shoe mounted. External floating roof tanks have numerous roof fittings that pass through or are attached to a floating roof to allow for operational functions. The most common roof fittings which are sources of evaporative losses include access hatches, guide pole wells, guide pole/sample wells, gauge float wells, gauge hatches/sample wells, vacuum breakers, roof drains, roof legs, and rim vents. More information on these fittings can be found in API's forthcoming Publication 2517.[17]



Pontoon Type



Double-Deck Type

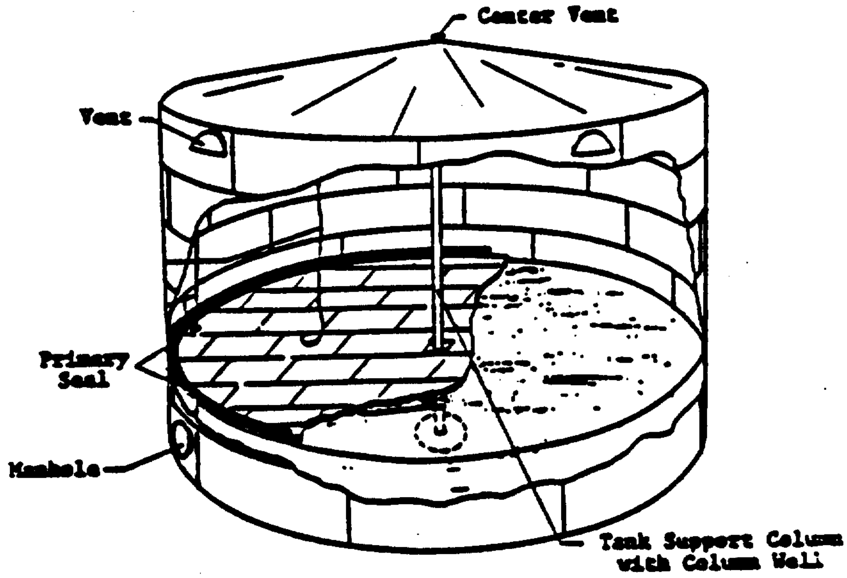
Figure 2. Typical external floating roof storage tanks.

Emissions from external floating roof tanks are the sum of standing storage loss and withdrawal loss. The standing storage loss can be estimated as the sum of rim seal loss and roof fitting loss. Rim seal loss occurs from evaporation of the liquid through and past the primary and/or secondary seals. Roof fitting loss results from roof fittings that require openings in the floating roof. There is no deck seam loss because the decks have welded sections. Withdrawal loss occurs as the liquid that clings to the tank wall is exposed to the atmosphere and vaporized when the floating roof is lowered by withdrawal of the stored liquid. Although relatively minor losses occur from evaporation during withdrawal of stored liquid, extremely frequent turnover of liquid in an external floating roof tank can increase the significance of withdrawal loss.

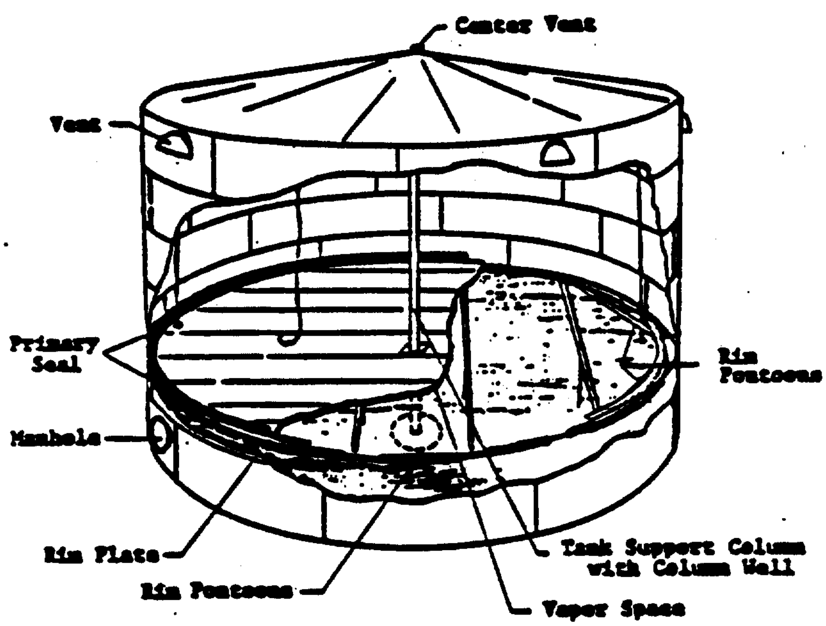
3.3 INTERNAL FLOATING ROOF TANKS

An internal floating roof tank has both a permanent fixed roof and an internal floating deck. Typical contact deck and noncontact deck internal floating roof tanks are shown in Figure 3. The terms "deck" and "floating roof" can be used interchangeably in reference to the structure floating on the liquid inside the tank. The purpose of the internal deck is to eliminate the "vapor space" in the tank, thereby limiting the amount of the stored liquid that evaporates and can be emitted. The deck rises and falls with the liquid level and either floats directly on the liquid surface (contact deck) or rests on pontoons several inches above the liquid surface (noncontact deck). Two basic types of internal floating roof tanks are tanks in which the fixed roof is supported by vertical columns within the tank and tanks with a self-supported fixed roof and no internal support columns. Fixed roof tanks that have been retrofitted to employ a floating deck are typically of the first type, while external floating roof tanks that have been retrofitted to employ a floating deck typically have a self-supported roof. Tanks initially constructed with both a fixed roof and a floating deck may be of either type.

Contact decks can be aluminum panels with a honeycomb aluminum core floating in contact with the liquid, or pan steel decks floating in contact with the liquid. Noncontact decks typically have an aluminum deck



Contact Deck Type



Noncontact Deck Type

Figure 3. Typical internal floating roof tanks.

or an aluminum grid framework supported above the liquid surface by tubular aluminum pontoons or other buoyant structures. Both types of decks incorporate rim seals, which slide against the tank wall as the deck moves up and down. Floating roofs may have primary and secondary seals. Three types of primary seals are generally used: vapor mounted, liquid mounted, and mechanical shoe. Secondary seals, which are usually vapor mounted, are used to further reduce emissions from internal floating roof tanks. In addition, these tanks are freely vented by circulation vents both at the top of the fixed roof and at the top of the shell. The vents minimize the possibility of organic vapor accumulation in concentrations approaching the flammable range. An internal floating roof tank not freely vented is considered a pressure tank.

Losses from internal floating roof tanks are the sum of withdrawal and standing losses. Withdrawal losses for internal floating roof tanks include vaporization of liquid that clings to the tank wall and columns, if present in tanks with a column supported fixed roof. Standing storage losses include rim seal, deck fitting, and deck seam losses. Rim seal losses include evaporative losses from the seals. Deck fitting losses result from penetrations in the roof by deck fittings, fixed roof column supports, or other openings. Deck seam losses occur when roofs are bolted. Welded roofs have no seams and thus no seam losses. Emissions from internal floating roof tanks may be reduced by using liquid mounted primary seals, continuous rim mounted secondary seals, welded decks, gasketted fittings, and flexible fabric seals to cover pipe columns.

3.4 VARIABLE VAPOR SPACE TANKS

Variable vapor space tanks are equipped with expandable reservoirs to accommodate vapor volume fluctuations attributable to temperature and barometric pressure changes. Although variable vapor space tanks are sometimes used independently, they are normally connected to the vapor spaces of one or more fixed roof tanks. The two most common types of variable vapor space tanks are lifter roof tanks and flexible diaphragm tanks.

Lifter roof tanks have a telescoping roof that fits loosely around the outside of the main tank wall. The space between the roof and the wall is closed by either a wet seal, which is a trough filled with liquid, or a dry seal, which uses a flexible coated fabric.

Flexible diaphragm tanks use flexible membranes to provide expandable volume. They may be either separate gasholder units or integral units mounted atop fixed roof tanks.

Variable vapor space tank losses occur during tank filling when vapor is displaced by liquid. Loss of vapor occurs only when the tank's vapor storage capacity is exceeded. Although an equation for estimating losses from variable vapor space tanks is available in AP-42, the accuracy of the equation is not documented. Losses estimated using this equation could differ significantly from actual emissions. Therefore, emissions from variable space tanks are not discussed further in this document.

3.5 PRESSURE TANKS

Two classes of pressure tanks are in general use, low pressure (1.5 to 14.7 psig) and high pressure (higher than 14.7 psig). Pressure tanks generally are used for storage of organic liquids and gases with high vapor pressures and are found in many sizes and shapes, depending on the operating pressure of the tank. Pressure tanks are equipped with a pressure/vacuum vent that is set to prevent venting loss from boiling and breathing loss from daily temperature or barometric pressure changes. High pressure storage tanks are usually operated so that virtually no evaporative or working losses occur. In low pressure tanks, working losses can occur with atmospheric venting of the tank during filling and withdrawal operations. Vapor recovery systems are generally used on low pressure tanks to reduce working losses. No appropriate correlations are available to estimate vapor losses from pressure tanks. Therefore, this document does not include any further discussion of emissions from pressure tanks.

4.0 SOURCE CATEGORY DESCRIPTION

This section presents three industrial source categories that use storage tanks and have the potential to emit air toxics. A brief description of each source category and available tank size and control device information are also presented in this section. The U. S. Environmental Protection Agency has published a document entitled "Toxic Air Pollutant/Source Crosswalk--A Screening Tool for Locating Possible Sources Emitting Toxic Air Substances" that cross-references industrial SIC codes, SCC codes, and air toxics for a variety of processes, including storage tanks.[4] The reader is directed to that document to identify which air toxics are known to be associated with a given industry.

Organic liquids are stored in above ground and below ground storage tanks, both of which may be significant sources of air toxics emissions. Underground storage tanks are defined as having 10 percent or more of their volume (including pipes) underground. Losses from underground storage tanks (excluding losses due to leaks in the tank system) result from filling and withdrawal operations. An estimated 1.4 million underground storage tanks are located in the United States.[5] Ninety six percent of these tanks are used to store petroleum products and the remaining 4 percent are used to store large volumes of industrial chemicals such as acetone, toluene, methyl ethyl ketone, methylene chloride, styrene, chloroform, methyl isobutyl ketone, ethylene dichloride, 1,1,1-trichloroethane, and ethylene oxide.[5] Because the accuracy of equations for estimating emissions from underground storage tanks is not documented, emissions from those tanks are not discussed further in this document.

Storage tanks can be divided into two groups based on type of stored material: industrial organic chemicals and petroleum liquids. The majority of storage tanks are located onsite at manufacturing and producing facilities. Some tanks also are located at bulk terminals. Of the total tank population, approximately 56 percent are estimated to be located at petroleum refineries, 38 percent at organic chemical industrial facilities, and 6 percent at bulk terminals.[6] Petroleum storage tanks generally store multicomponent liquids whereas organic chemical storage tanks usually contain single component liquids. The type of tank used to store liquids is dependent primarily on the volume of liquid to be stored annually and the vapor pressure of the liquid. Other factors that influence the selection of the tank type include material stability, safety hazards, and multiple use of tank for different liquids. The following subsections present information about industrial organic chemical storage tanks, petroleum refineries, and bulk terminals storage tanks.

4.1 INDUSTRIAL ORGANIC CHEMICAL STORAGE TANKS

Most organic chemicals, with the exception of petroleum products, are stored as single component liquids in tanks. It is assumed that the composition of the liquids in these storage tanks is 100 percent of the chemical.

Organic chemical storage tanks are located primarily at chemical producing and manufacturing facilities. Some industrial organic chemicals are stored offsite at bulk terminals. It is estimated that only a small percentage of the total volume of industrial organic chemicals are stored in tanks off site at bulk terminals.[1,6] The majority of emissions from organic chemical storage tanks result from producers. About one-quarter of air toxic emissions from organic chemical storage tanks result from consumers. The remainder of emissions from industrial organic chemical storage tanks originate from bulk terminal tanks.[7]

The onsite tanks at organic chemical production and consumer facilities are used to store raw materials, final products, and/or usable by-products as well as waste tars, residues, and nonusable products. The major producers of industrial organic chemicals have SIC codes 286x. Producers are located in all areas of the U.S., with the largest plants clustered in the Central Southern States near raw material supplies and in the Mid-Atlantic States close to industries.

Industrial organic chemical tanks located at consuming facilities are generally associated with industries having SIC codes 28xx. The majority of emissions from organic chemical storage tanks located at consuming facilities are estimated to originate from the plastics industry. Other consuming facilities that have organic chemical storage tanks manufacture surface active agents, pharmaceuticals, textiles, nitrogen fertilizer, rubber and miscellaneous synthetics, and treated wood. The major types of chemicals stored by these facilities include dyes, toners, creosote oil, rubber processing chemicals, and plasticizers. Storage tanks present at organic chemical consuming/manufacturing facilities are typically small, less than 40,000 gallons. Facilities where chemicals are prepared for distribution generally have tanks less than 20,000 gallons in size.[7] Industrial organic chemical consuming facilities are fairly evenly distributed across the U.S. with some tendency to be located in South Atlantic and Eastern Central States.

The majority of storage tanks located at industrial organic chemical production and manufacturing facilities are fixed roof tanks. Fixed roof tanks are used predominantly for storing materials with vapor pressures of 5 psia or less. Although fixed roofs are used more than floating roof tanks, volatile organic liquid storage tanks regulations will probably result in the increasing use of floating roof tanks.[1]

Most fixed roof tanks and internal floating roof tanks store liquids with vapor pressures less than 5 psia and have volumes of 100,000 gallons or less. External floating roofs are generally used to store liquid volumes of 130,000 gallons or more. The majority of industrial organic chemical tanks are small, with volumes of less than 20,000 gallons. However, the majority of emissions from storage tanks are estimated to originate from tanks with capacities greater than 20,000 gallons and which store liquids with vapor pressures greater than 0.5 psia.[7]

Horizontal tanks are used widely in the Synthetic Organic Chemical Manufacturing Industry (SOCMI). The volumes of horizontal tanks are typically small and rarely exceed 30,000 gallons. Horizontal tanks are preferred for separation processes. These tanks typically require add-on control systems such as carbon adsorption or thermal oxidation.[1,6]

Organic liquids with vapor pressures greater than 11 psia are stored in high pressure tanks or have a vapor recovery system. High pressure tanks generally are used to store highly volatile and/or toxic materials.

4.1.1 Chlorinated Solvents[8,9]

Chlorinated solvents are stored at producing and consuming facilities. Some common chlorinated solvents are methylene chloride, carbon tetrachloride, trichloroethylene, and perchloroethylene.

The information presented for this subsection comes from the source assessment documents for two chlorinated solvents, methylene chloride and trichloroethylene. The information in those documents was taken from EPA questionnaire responses. Storage tank information was available for facilities that produce the solvents and for facilities that use the solvents as feedstocks in other processes. The level of control required for the storage tanks represented in these documents may change due to future regulations.

Almost all of the storage tanks represented in the source assessment documents are fixed roof tanks. The tanks ranged in size from 250 to 500,000 gallons with the average size in the range of 25,000 to 50,000 gallons. In most cases, no control devices were used with the tanks. For the few cases where a control device was used, the majority were water-cooled condensers.

Pressure vessels of less than 1,000 gallons were reportedly being used to store chlorinated solvents in a few cases. The only type of storage tank other than fixed roof reported in the source assessment documents was a contact internal floating roof tank of approximately 500,000 gallons with no control device.

4.1.2 Nonchlorinated Solvents[10,11,12]

A variety of nonchlorinated solvents are stored at manufacturing facilities. Most of these solvents are stored in small fixed roof tanks. Some facilities use control devices; however, most small tanks (less than 20,000 gallons) are not required to have controls. This subsection presents information about two industries, polymeric coating and magnetic tape manufacturing.

Polymeric coating facilities store solvents in small, fixed roof tanks. The solvents generally stored include toluene, dimethyl formamide, acetone, methyl ethyl ketone, xylene, isopropyl alcohol, and ethyl acetate. Toluene is the most commonly used solvent because it is relatively inexpensive. Most polymeric coating facilities store single solvents rather than multicomponent solvents. Each polymeric coating facility usually has five or less solvent storage tanks. The tank capacity typically ranges from 1,000 to 20,000 gallons. The majority of solvent storage tanks are underground. However, it is likely that new solvent storage tanks will be built above ground because of concern over potential groundwater contamination. No add-on control devices are currently being used to control the tanks. More than 100 polymeric coating facilities are located throughout the U.S., with the heaviest concentration being in the Northeast. The SIC codes associated with these facilities are 2241, 2295, 2296, 2394, 2641, 3041, 3069, and 3293. Approximately 50 percent of the polymeric coated products are manufactured by industries with SIC codes of 2295 and 2296 for use in automobiles.

Magnetic tape manufacturing facilities generally store multicomponent solvents in fixed roof tanks. The solvents stored include tetrahydrofuran, methyl ethyl ketone, methyl isobutyl ketone, toluene, and cyclohexanone. The capacity for magnetic tape solvent vessels ranges from 1,000 to 20,000 gallons. The solvent tanks may be vertical or horizontal fixed roof tanks. A few of the tanks are located underground. Most of the tanks are operated at atmospheric pressure or slightly above. Conservation vents are used by some facilities to minimize tank losses. A conservation vent is a combination pressure and vacuum relief valve that protects closed tanks from physical damage during filling and withdrawal of liquid or from damage due to high pressure or vacuums. Conservation vents cannot be installed in some tanks because of the resulting higher internal pressure. Solvent storage tank emissions may also be controlled by venting vapor into control devices such as carbon adsorbers. Proposed regulations require new solvent tanks at magnetic tape manufacturing facilities to install pressure relief valves or to capture and vent all emissions to a 95 percent efficient control device.[11] Magnetic tape facilities are located in 15 States, with California having the largest number of plants. The SIC codes associated with magnetic tape manufacturers are 3679 and 3573.

4.2 PETROLEUM REFINERIES[13]

The products stored at petroleum refineries can be divided into three categories: low vapor pressure products, high vapor pressure products, and crude oil. Benzene, toluene, and xylene are air toxics commonly associated with petroleum products. Some general information about storage practices for these three categories is presented below.

Low vapor pressure petroleum refinery products, such as fuel oil and diesel fuel, are typically stored in large fixed roof storage tanks. Fixed roof tanks, which have generally higher emission rates than floating roof tanks, are allowed by Federal and State regulations to be used because of the products' low vapor pressures. Additional control devices (e.g., condensers) are not typically employed on these fixed roof tanks.

High vapor pressure products, such as gasoline, are typically stored in large external floating roof tanks. These tanks range in diameter from 50 to 180 feet and are typically 30 to 50 feet high. No add-on control devices are typically used with these tanks. Some of the tanks have been modified to be internal floating roof tanks. External floating roof tanks are required by State and Federal regulations to have both a primary and secondary seal. The primary seal is usually a mechanical shoe seal and the secondary seal is usually rim-mounted. Petroleum refineries also store other high vapor pressure products, such as benzene, in internal floating roof tanks that range in volume between 100,000 and 500,000 gallons.

The third category of petroleum refinery products is crude oil. Crude oil has a wide ranging vapor pressure. Crude oil is usually stored in large external floating roof tanks.

4.3 BULK TERMINAL STORAGE TANKS[13]

Bulk terminals are nonmanufacturing sites that store commodities in large quantities. Petroleum liquid products are stored primarily at bulk terminals, while only a small amount of industrial organic liquids are stored at bulk terminals. The remainder of this subsection focuses on the storage of petroleum liquids after leaving a petroleum refinery.

Petroleum products are stored at two types of terminals, high volume and low volume. External floating roof tanks are used at both high-volume and low-volume terminals. Most of the petroleum tanks at terminals have installed vapor recovery systems because of Federal and State regulations.

High-volume terminals are pipeline endpoints and typically have very large external floating roof tanks. The average volume of tanks at a high volume bulk terminal is 871,000 gallons.[6] At high volume terminals, the average smallest sized tank is estimated to be 319,000 gallons and the average largest sized tank is estimated to be 3,600,000 gallons.[7] The majority of high-volume storage terminals are located in Texas, New Jersey, and Louisiana. Large petroleum distribution terminals also are located in Central and Southern States.

Low-volume terminals generally are used for local distribution of gasoline. These tanks also have external floating roofs, but are smaller in size than tanks at high-volume bulk terminals. Tanks at small bulk terminals range in size from 40,000 to 100,000 gallons.

After leaving bulk terminals, gasoline is transported to local gasoline stations. Gasoline is usually stored in underground horizontal tanks of between 10,000 and 20,000 gallons.

5.0 ESTIMATING AIR TOXICS EMISSIONS

Emissions of toxic organic compounds from storage tanks are a function of the size and type of tank, the vapor pressure of the liquid inside the tank, and atmospheric conditions at the tank location. Three types of tanks are usually used to store organic liquids: fixed roof, external floating roof, and internal floating roof. Fixed roof storage tank emissions are the sum of breathing losses (which are due to changes in ambient temperature or pressure) and working losses (from loading and unloading the tank). External floating roof and internal floating roof storage tank emissions are the sum of standing storage loss and withdrawal loss. Standing storage loss includes rim seal loss, deck fitting loss, and deck seam loss.

The EPA Publication AP-42 contains equations to estimate emissions of petroleum products and volatile organic liquids from fixed roof and external or internal floating roof tanks. These equations have been used to obtain emission estimates for organic compounds. When using these equations, it is important to recognize that results from the equations are only estimates.

The following section presents the AP-42 emission estimating equations for fixed roof tanks, external floating roof tanks, and internal floating roof tanks and describes the methodology for the selection of parameters and calculation of properties. Table 1 shows the calculation methodology recommended to estimate storage tank emissions. This section discusses each of the 11 steps in the calculation methodology.

The equations are not intended to be used in the following applications: (1) to estimate losses from unstable or boiling stocks, (2) to estimate losses from mixtures of hydrocarbons or petrochemicals for which the vapor pressure is not known or cannot be readily predicted, (3) to estimate breathing losses from insulated fixed roof tanks (the equations for working losses are still valid), or (4) to estimate losses from tanks in which the materials used in the rim seal system and/or roof fittings are either deteriorated or significantly permeated by the stored liquid.

TABLE 1. CALCULATION METHODOLOGY

1.	Determine tank type
2.	Determine estimating methodology
3.	Select equations to be used
4.	Identify parameters to be calculated or determined from tables
5.	Calculate mole fractions in the liquid
6.	Calculate partial pressures and total vapor pressure of the liquid
7.	Calculate mole fractions in the vapor
8.	Calculate molecular weight of the vapor
9.	Calculate weight fractions of the vapor
10.	Calculate total VOC emitted from the tank
11.	Calculate amount of each component emitted from the tank

One of the most important parameters in estimating emissions from storage tanks is the vapor pressure of the liquid being stored. The vapor pressure of a liquid is a function of temperature and is affected by process changes. The equations are more appropriate for substances with vapor pressures of approximately 1.5 psia to 14.7 psia. The equations have been developed for tanks having diameters greater than 20 feet and having average wind speed ranging from 2 to 15 miles per hour. A methodology to estimate emissions from low vapor pressure substances stored in tanks is currently under development.[2] Table A-2 contains vapor pressure information for several common organic compounds.[1,7,8] When two or more compounds are present in a mixture, the resulting vapor pressure must either be calculated analytically or determined through measurements. The analytical method most frequently used to estimate vapor pressure is Raoult's Law. Raoult's Law states that the vapor pressure exerted by a component in a mixture is equal to the mole fraction of the component times the vapor pressure of the component.

Raoult's Law in equation form is: $P_{i,t} = P^{o}_{i,t}x_i$, where $P_{i,t}$ is the pressure exerted by component i in the mixture at temperature t, $P^{o}_{i,t}$ is the vapor pressure of the pure component i at temperature t, and x_i is the mole fraction (as defined in Note (1) of Section 5.1) of component i in the liquid mixture. Raoult's Law is valid only for compounds that form ideal mixtures. Some mixtures behave in a nearly ideal manner because their components have similar structures and molecular weights. Common organic functional groups that have an effect on the ideality of a mixture (i.e., make Raoult's Law in applicable) are:

Acid anhydride	Ester
Alcohol	Ether
Aldehyde	Ketone
Amide	Nitrile
Amine	Thiol
Carboxylic acid	

Mixtures that contain compounds with different functional groups will not behave ideally. However, compounds with similar functional groups can be assumed to behave ideally, allowing the use of Raoult's Law. Raoult's Law cannot be applied to complex mixtures of hydrocarbons such as petroleum stocks. If the vapor pressure of a mixture cannot be estimated accurately using Raoult's Law, it can be estimated through sampling and analysis or chemical equilibrium data, if available.

Several examples demonstrating the use of the storage tank emission equations are presented in Appendix B. A summary of all variables used in the emission estimating equations is presented in Table B-1.

5.1 DETERMINE TANK TYPE

This report presents equations for estimating emissions from three types of tanks: fixed roof, external floating roof, and internal floating roof. Before selecting the appropriate equations, the user must categorize the storage tank. Section 3 presents discussions and schematics of the three types of tanks plus pressure tanks and variable vapor space tanks. If there is a question as to what type a particular storage tank is, Section 3 should be consulted.

5.2 DETERMINE ESTIMATING METHODOLOGY

When estimating emissions from a storage tank, the parameters used in the equations must be determined. Usually, the identity and concentration of the constituents in a mixture are known or can be easily calculated. The vapor pressure of the liquid mixture must then be determined through one of three methods: (1) read from a table, (2) calculated using Raoult's Law if the mixture acts ideally, or (3) measured using sampling and analysis of the vapor. The vapor pressure of mixtures such as gasoline can be obtained from Table A-2 or Figure A-4. If the compounds in the mixture have similar structures and molecular weights (see Section 5.0), then Raoult's Law can be used. However, if the compounds are dissimilar, then an accurate vapor pressure for the mixture can only be obtained through sampling and analysis of vapor in the tank.

The molecular weight and the composition of the vapor must be calculated if they cannot be located in a table. These parameters can be calculated from the liquid composition and liquid component properties.

5.3 SELECT EQUATIONS TO BE USED

AP-42 presents emission equations for three types of storage tanks: fixed roof, external floating roof, and internal floating roof. The equations for these tanks are presented below.

5.3.1 Fixed Roof Tanks

The following equations apply to tanks with vertical cylindrical shells and fixed roofs. These tanks store primarily liquid and operate approximately at atmospheric pressure. The breathing loss equations do not apply to insulated fixed roof tanks. Total VOC losses from fixed roof tanks can be estimated as:

$$L_T = L_B + L_W \tag{1}$$

where:

L_T = total loss, lb/yr
L_B = fixed roof breathing loss, lb/yr
L_W = fixed roof working loss, lb/yr

Breathing loss:

Fixed roof tank breathing losses can be estimated as:

$$L_B = 2.26 \times 10^{-2} M_V \left(\frac{P}{P_A - P}\right)^{0.68} D^{1.73} H^{0.51} \Delta T^{0.50} F_P C K_C \tag{2}$$

where:

M_V = molecular weight of vapor in storage tank, lb/lb-mol, see Note 1
P = true vapor pressure at bulk liquid conditions, psia, see Note 2
P_A = average atmospheric pressure at tank location, psia
D = tank diameter, ft
H = average vapor space height, including roof volume correction, ft, see Note 3
ΔT = average ambient diurnal temperature change, °F
F_P = paint factor, dimensionless, see Table A-1
C = adjustment factor for small diameter tanks (dimensionless), see Figure A-1, see Note 4

K_C = product factor (dimensionless), see Note 5

For horizontal tanks, see Note 6.

Working loss:

Fixed roof tank working losses can be estimated as:

$$L_W = 2.40 \times 10^{-5}\ M_V P V N K_N K_C \qquad (3)$$

where:

V = tank capacity, gal

N = number of turnovers per year, dimensionless

$$N = \frac{\text{total throughput per year, gal}}{\text{tank capacity, gal}}$$

K_N = turnover factor, dimensionless, see Figure A-2

for turnovers >36, $K_N = \frac{180+N}{6N}$

for turnovers ≤ 36, $K_N = 1$

M_V, P, and K_C are as defined for Equation 2.

Notes: (1) M_V can be determined by Table A-2 for selected petroleum liquids and volatile organic liquids or estimated using the following equation

$$M_V = \Sigma M_i \frac{P_i x_i}{P_T} = \Sigma M_i \frac{P_{partial}}{P_T} = \Sigma M_i y_i$$

where:

M_V = molecular weight of the vapor

M_i = molecular weight of the component i

P_i = vapor pressure of the pure component i at the temperature of the liquid

x_i = mole fraction of the component i in the liquid

P_T = total vapor pressure of the liquid

$P_{partial}$ = partial pressure of the component i

y_i = mole fraction of the component in the vapor

The molecular weight of the vapor is dependent upon the molecular weight and the vapor mole fraction of each component. The mole fraction of a component is the number of moles of that component divided by the total number of moles in the mixture. The number of moles of a component in a mixture (liquid or vapor) is calculated by dividing the weight of the component by its molecular weight. For a given component, the product of its liquid mole fraction and its vapor pressure is called the partial pressure of the component (this is Raoult's Law). This is the amount of pressure in the vapor that is due to that component in the liquid. The ratio of the partial pressure of a component to the total vapor pressure is equal to the mole fraction of that component in the vapor.

(2) True vapor pressures for organic liquids can be determined from Figures A-3 or A-4, Table A-2, or by calculation. The stored liquid temperature, T_S, must be known in any case and may be calculated by knowing the color of the tank and the average ambient temperature in the area. Table A-3 shows T_S as a function of ambient temperature and tank color. Table A-4 shows average ambient temperatures for selected U.S. locations.

(3) If information is not available on the vapor space height, assume H equals one half the corrected tank height. To correct for a cone roof, the vapor space in the cone is equal in volume to a cylinder which has the same base diameter as the cone and is one third the height of the cone.

(4) The small tank diameter adjustment factor, C, can be read from Figure A-1 or calculated using the

following equations:

for diameter $\geq$30 feet, C = 1

for diameter <30 feet, $C = 0.0771(D)-0.0013(D^2)-0.1334$

(5) For crude oil, $K_C = 0.65$. For all other organic liquids, $K_C = 1.0$.

(6) The emission estimating equations presented in Section 5.3.1 were developed for vertical fixed roof tanks. If a user needs to estimate emissions from a horizontal fixed roof tank, some of the tank parameters can be modified before using the vertical tank equations. First, by assuming that the tank is one-half filled, the surface area of the liquid in the tank is approximately equal to the length of the tank times the diameter of the tank. Next, assume that this area represents a circle, i.e., that the liquid is in an upright cylinder. The diameter of that circle can be solved for and used in the equations as D. One-half of the diameter of horizontal tank should be used as the value for H. This method yields only a very approximate value for emissions from horizontal fixed roof storage tanks.

5.3.2 External Floating Roof Tanks

Floating roof tank emissions are the sum of rim seal, withdrawal, and roof fitting losses. External floating roof tanks do not have deck seam losses. The equations have been developed for liquids that are not boiling, stocks with a true vapor pressure ranging from 1.5 to 14.7 psi, average wind speeds ranging from 2 to 15 mph, and tank diameter of 20 ft or greater. The equations are applicable to properly maintained equipment in normal working conditions where materials used in the rim seal system and/or roof fittings are not deteriorated or significantly permeated by the stored liquid. Losses from poorly maintained equipment may be higher than losses estimated using the equations.

Emissions from external floating roof tanks can be estimated as:

$$L_T = L_R + L_{WD} + L_{RF} \qquad (4)$$

where:

L_T = total loss, lb/yr

L_R = rim seal loss, lb/yr

L_{WD} = withdrawal loss, lb/yr

L_{RF} = roof fitting loss, lb/yr

L_D = deck seam loss, lb/yr, = 0.0;

<u>Rim seal loss</u>:

Rim seal loss from floating roof tanks can be estimated by the following equation:

$$L_R = K_S v^n p^* D M_V K_C \qquad (5)$$

where:

K_S = seal factor for average or tight fit seals, lb-mol/(ft [mi/h]^n yr), see Table A-5

v = average wind speed at tank site, mi/h, see Note 1

n = seal-related wind speed exponent (dimensionless), see Table A-4

p^* = vapor pressure function (dimensionless), see Note 2

$$p^* = \frac{\frac{P}{P_A}}{\left[1+\left(1-\frac{P}{P_A}\right)^{0.5}\right]^2} \qquad (6)$$

where:

P = true vapor pressure at average actual liquid storage temperature, psia, see Note 2 to Equation 1

P_A = average atmospheric pressure at tank location, psia

D = tank diameter, ft

M_V = average vapor molecular weight, lb/lb-mol, see Note 1 to Equation 1

K_C = product factor, dimensionless, see Note 3

Figures A-6 through A-9 present graphical estimates of ($K_S v^n$) for several tank and seal types.

Notes: (1) Wind speed data are presented in Table A-6. If the wind speed at the tank site is not available, wind speed data from the nearest local weather station may be used as an approximation.

(2) P* can be calculated or read directly from Figure A-5.

(3) For all organic liquids except crude oil, $K_C = 1.0$. For crude oil, $K_C = 0.4$.

Withdrawal loss:

The withdrawal loss from floating roof storage tanks can be estimated using the following equation:

$$L_{WD} = \frac{(0.943)QC_F W_L}{D}\left[1+\frac{N_C F_C}{D}\right] \quad (7)$$

where:

Q = annual throughput, bbl/yr (tank capacity [bbl] times annual turnover rate)

C_F = shell clingage factor, bbl/1,000 ft^2, see Table A-7, Note 1

W_L = average organic liquid density, lb/gal, see Note 2

D = tank diameter, ft

N_C = number of columns, dimensionless, see Note 4

F_C = effective column diameter, ft (column perimeter [ft]/π), see Note 5

Notes: (1) The units on this parameter, bbl/1,000 ft^2, are cancelled out by the units on the constant 0.943 (see Note 3). Therefore, if the appropriate C_F value from Table A-7 is 0.0015 bbl/1,000 ft^2, the number 0.0015 should be used in the equation for C_F.

(2) If W_L is not known, an average value of 5.6 lb/gal can be assumed for gasoline. An average value cannot be assumed for crude oil, since densities are highly variable.

(3) The constant, 0.943, has dimensions of 1,000 ft^3xgal/bbl^2.

(4) For self-supporting fixed roof or an external floating roof tank:

$$N_C = 0$$

For internal floating roof tank with column-supported fixed roof:

N_C = use tank-specific information, or see Table A-12

(5) For internal floating roof tank with column-supported fixed roof, use tank-specific effective column diameter; or

F_C = 1.1 for 9-inch by 7-inch builtup columns, 0.7 for 8-inch diameter pipe columns, and 1.0 if column construction details are not known.

Roof fitting loss:

Fitting losses from external floating roof tanks can be estimated by the following equation:

$$L_{RF} = F_F P^* M_V K_C \tag{8}$$

where:

F_F = total roof fitting loss factor, lb-mol/yr

$= [(N_{F_1} K_{F_1}) + (N_{F_2} K_{F_2}) \; . \; . \; . + (N_{F_{n_f}} K_{F_{n_f}})]$

where:

N_{F_i} = number of deck fittings of a particular type ($i = 0,1,2,\ldots,n_f$), dimensionless, see Table A-8, A-9, A-10

K_{F_i} = roof fitting loss factor for a particular type fitting ($i = 0,1,2,\ldots,n_f$), lb-mol/yr, see Equation 9 or Figures A-10 through A-18

n_f = total number of different types of fittings, dimensionless

P^*, M_V, K_C = as defined for Equations 5 and 6

The roof fitting loss factor for a particular roof fitting type, K_{F_i}, can be read directly from Figures A-10 through A-18 or calculated using Equation 9. Figures A-10 through A-18 show roof fitting loss factors based on wind speed for common roof fitting types. The roof fitting loss factor for individual fitting types can also be estimated from Equation 9:

$$K_{F_i} = K_{fa_i} + K_{fb_i} \, v^{m_i} \quad (9)$$

where:

K_{fa_i} = roof fitting loss factor for a particular roof fitting type (i = 1, 2, ..., n)(lb-mol/yr).

K_{fb_i} = roof fitting loss factor for a particular roof fitting type [i = 1, 2, ..., n][lb-mol/(mi/h)^{m}yr].

m_i = roof fitting loss factor for a particular roof fitting type (i = 1, 2, ..., n)(dimensionless).

v = average wind speed (mi/h).

The most common roof fittings and their associated roof fitting loss factors, K_{fa_i}, K_{fb_i}, and m_i are presented in Table A-8.

The number of each type of roof fitting, N_{F_i},can vary significantly from tank to tank and should be determined for each tank under consideration. If specific tank information is not available, N_{F_i} can be obtained from Tables A-8, A-9, and A-10. Table A-8 presents the typical number of fittings associated with the most common roof fittings. Tables A-9 and A-10 show the typical number of vacuum breakers, roof drains, and roof legs based on tank diameter.

If no information is available on the specific type and number of roof fittings, the total roof fitting loss factor, F_F, can be obtained from Figures A-19 and A-20. Figures A-19 and A-20 show total roof fitting loss factors based on tank diameter for typical roof fittings on pontoon and double-deck floating roofs, respectively. These total loss factors should only be used when detailed roof fitting information is not available.

Deck seam loss:

External floating roof tanks do not have deck seam losses because roofs are welded. Equations for deck seam losses are presented for internal floating roof tanks in Section 5.3.3.

5.3.3 Internal Floating Roof Tanks

The equations provided in this section are applicable only to freely vented internal floating roof tanks. These equations are not intended to estimate losses from closed internal floating roof tanks (tanks vented only through a pressure/vacuum vent).

Emissions from internal floating roof tanks may be estimated as:

$$L_T = L_R + L_{WD} + L_F + L_D \qquad (10)$$

where:

L_T = total loss, lb/yr

L_R = rim seal loss, see Equation 5

L_{WD} = withdrawal loss, see Equation 7

L_F = deck fitting loss, lb/yr

L_D = deck seam loss, lb/yr

<u>Deck fitting losses</u>:

Fitting losses from internal floating roof tanks can be estimated by the following equation:

$$L_F = F_F P^* M_V K_C \qquad (11)$$

where:

F_F = total deck fitting loss factor, lb-mol/yr

$= [(N_{F_1} K_{F_1}) + (N_{F_2} K_{F_2}) \ldots + (N_{F_{n_f}} K_{F_{n_f}})]$

where:

N_{F_i} = number of deck fittings of a particular type (i = 0, 1, 2, ..., n_f), dimensionless, see Table A-11

K_{F_i} = deck fitting loss factor for a particular type fitting (i = 0, 1, 2, ..., n_f), lb-mol/yr, see Table A-11

n_f = total number of different types of fittings

P^*, M_V, K_C = as defined in Equations 5 and 6.

The value of F_F may be calculated by using actual tank-specific data for the number of each fitting type (N_F) and then multiplying by the fitting loss factor for each fitting (K_F). Values of fitting loss factors and typical number of fittings are presented in Table A-11. Where tank-specific data for the number and kind of deck fittings are unavailable, then F_F can be approximated according to tank diameter. Figures A-21 and A-22 present F_F plotted against tank diameter for column-supported fixed roofs and self-supported fixed roofs, respectively.

Deck seam loss:

Welded internal floating roof tanks do not have deck seam losses. Deck seam losses may be present for tanks with bolted decks. Deck seam loss can be estimated by the following equation:

$$L_D = K_D S_D D^2 P^* M_V K_C \quad (12)$$

where:

K_D = deck seam loss per unit seam length factor, lb-mol/ft yr
= 0.0 for welded deck and external floating roof tanks,
= 0.34 for bolted deck

S_D = deck seam length factor, ft/ft^2

$$= \frac{L_{seam}}{A_{deck}}$$

where:

L_{seam} = total length of deck seams, ft

A_{deck} = area of deck, ft^2 = $\pi D^2/4$

D, P*, M_V, K_C = as defined for Equations 5 and 6

If the total length of the deck seam is not known, Table A-13 can be used to determine S_D. For a deck constructed from continuous metal sheets with a 7 ft spacing between the seams, a value of 0.14 ft/ft^2 can be used. A value of 0.33 can be used for S_D when a deck is constructed from rectangular panels 5 ft by 7.5 ft. Where tank-specific data concerning width of deck sheets or size of deck panels are unavailable, a default value for S_D can be assigned. A value of 0.20 ft/ft^2 can be assumed to represent the most common bolted decks currently in use.

5.4 IDENTIFY PARAMETERS TO BE CALCULATED OR DETERMINED FROM TABLES

Once the correct emission estimating equations have been identified, the user must identify the variables that are not specified by given conditions. By determining which factors (such as the number of columns in an internal floating roof tank) are not known and which can be determined from tables (e.g., the paint factor, the wind velocity exponent), the user can decide which calculation steps need to be performed.

5.5 CALCULATE MOLE FRACTIONS IN THE LIQUID

This step is only necessary if the vapor pressure of the liquid is estimated using Raoult's Law. The number of moles of a component in a mixture (liquid or vapor) is equal to the weight of the component in the mixture divided by the molecular weight of the component. The mole fraction of a component is the number of moles of the component divided by the total number of moles in the mixture, including itself. Often mole fractions are calculated from weight fractions. For example, a stored liquid might be known to be 50 weight percent toluene, 35 weight percent benzene, and 15 weight percent aniline. By looking at an arbitrary amount of the liquid (1,000 pounds), the mole fractions of the three components can be determined. This is demonstrated in Part 5 of Example B-1. The mole fractions calculated for a mixture using an arbitrary amount of liquid are valid no matter what amount of the mixture is actually present.

5.6 CALCULATE PARTIAL PRESSURES AND TOTAL VAPOR PRESSURE OF THE LIQUID

This step is required only when the vapor pressure of the stored liquid is not known. Vapor presures of organic compounds are located in Table A-2. Vapor pressures for certain compounds also can be calculated using regression equations.[15,16] If the mixture behaves ideally, Raoult's Law is used to calculate the partial pressure of each component in the mixture. As explained in Section 5.0, Raoult's Law states that the mole fraction of the component in the liquid (x_i) times the vapor pressure of the component at the storage temperature ($P_{i,T}$) is equal to the partial pressure for that component. The sum of the partial pressures for all components in the mixture is the vapor pressure of the mixture. This is demonstrated in Step 6 of Example B-1.

5.7 CALCULATE MOLE FRACTIONS IN THE VAPOR

This step is only required when the weight fractions or the molecular weight of the vapor is not known. The mole fraction of a component in a vapor mixture is equal to the partial pressure of the component divided by the total vapor pressure of the liquid:

$$(y_i = \frac{P_{partial}}{P_{total}}).$$

This is demonstrated in Step 7 of Example B-1.

5.8 CALCULATE MOLECULAR WEIGHT OF THE VAPOR

This step is required only when the molecular weight of the vapor is not known. Since molecular weight is a molar quantity, the molecular weight of the vapor is dependent on the mole fractions of components in the vapor. This calculation is shown in Step 8 of Example B-1.

5.9 CALCULATE WEIGHT FRACTIONS OF THE VAPOR

This step is required only when the weight fractions of the vapor are not known. Vapor phase weight fractions for many mixtures are available in VOC species data manuals (see Reference 14). Weight fractions can also be calculated using the mole fractions from Step 7. For example, the vapor phase mole fractions might have been calculated as 50 percent toluene, 25 percent benzene, and 25 percent aniline. By looking at an arbitrary amount of the vapor (1,000 moles), the weight fractions of the three components can be determined. This is demonstrated in Step 9 of Example B-1. The weight fractions calculated for a mixture using an arbitrary amount of vapor are valid no matter what amount of the mixture is actually present.

5.10 CALCULATE TOTAL VOC EMITTED FROM THE TANK

Using the equations identified in Step 3 and the parameters calculated in Steps 4 through 8, the total VOC emitted from the storage tank can be calculated. This calculation is shown in Step 10 of Example B-1.

5.11 CALCULATE AMOUNT OF EACH COMPONENT EMITTED FROM THE TANK

The amount of each component emitted from the tank is the weight fraction of that component in the vapor (calculated in Step 9) times the amount of total VOC emitted (calculated in Step 10). For example, if a tank emits 1,000 pounds of VOC and the vapor weight fraction for benzene is 0.15, then 150 pounds of benzene is emitted. The liquid volume of a component emitted can be calculated by dividing the weight of the component emitted by the density (lb/gal) of the component. This is demonstrated in Step 11 of Example B-1.

6.0 REFERENCES

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15. Handbook of Physics and Chemistry. pp. D-212 through D-215, 67th Edition. CRC Press, Inc., 1986.

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APPENDIX A.

FIGURES AND TABLES

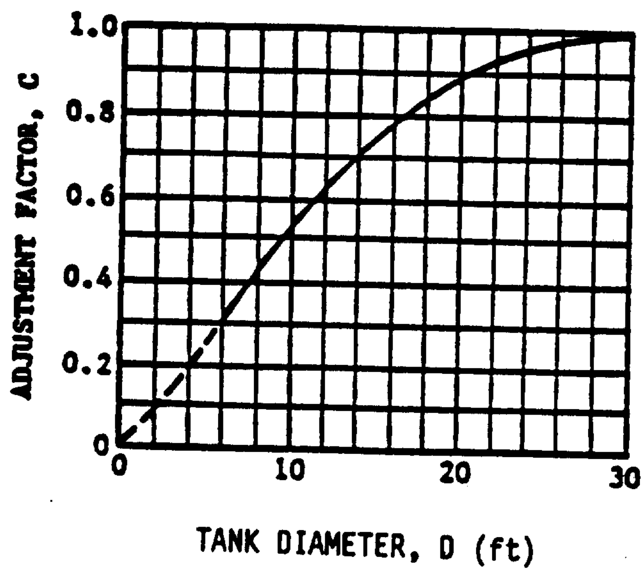
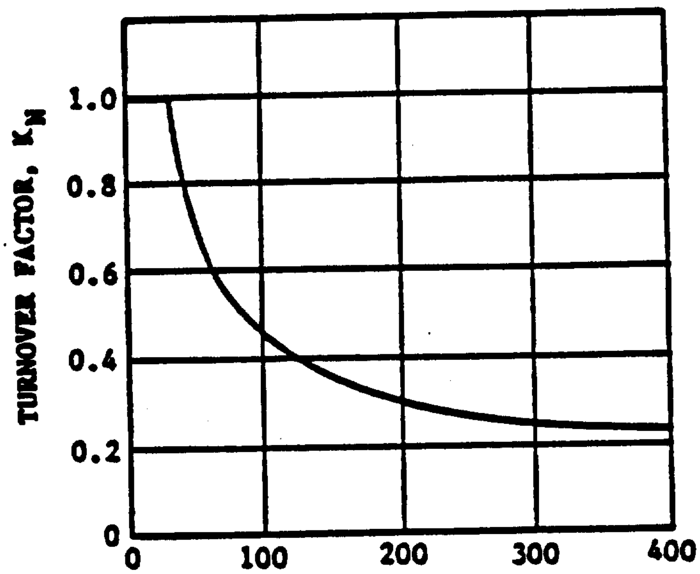


Figure A-1. Adjustment factor (C) for small diameter tanks.



$$\text{TURNOVERS PER YEAR, } N = \frac{\text{ANNUAL THROUGHPUT}}{\text{TANK CAPACITY}}$$

NOTE: FOR 36 TURNOVERS PER YEAR OR LESS, $K_N = 1.0$

FOR 36 TURNOVERS OR MORE PER YEAR,

$$K_N = \frac{180+N}{6N}$$

Figure A-2. Turnover factor (K_N) for fixed roof tanks.

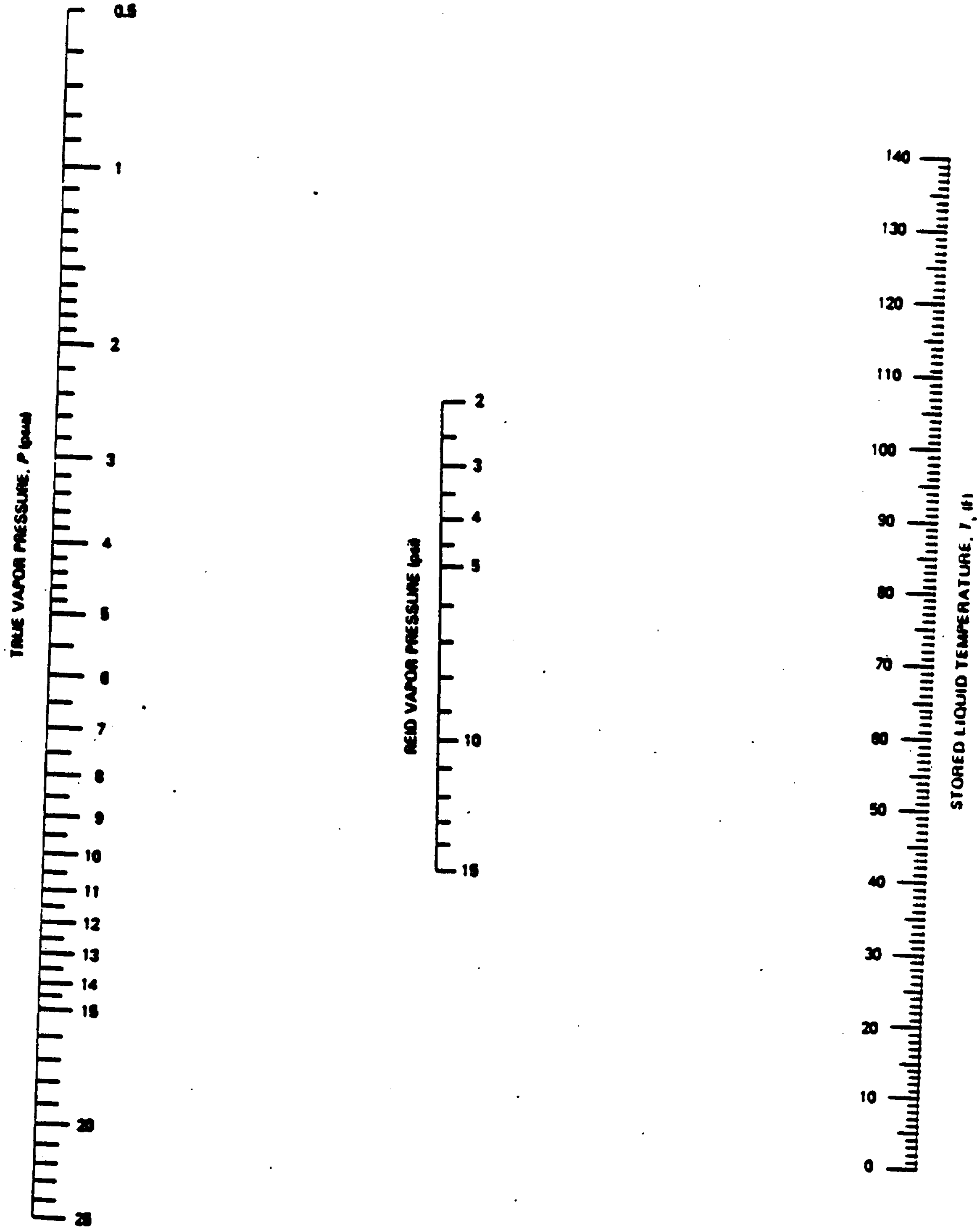
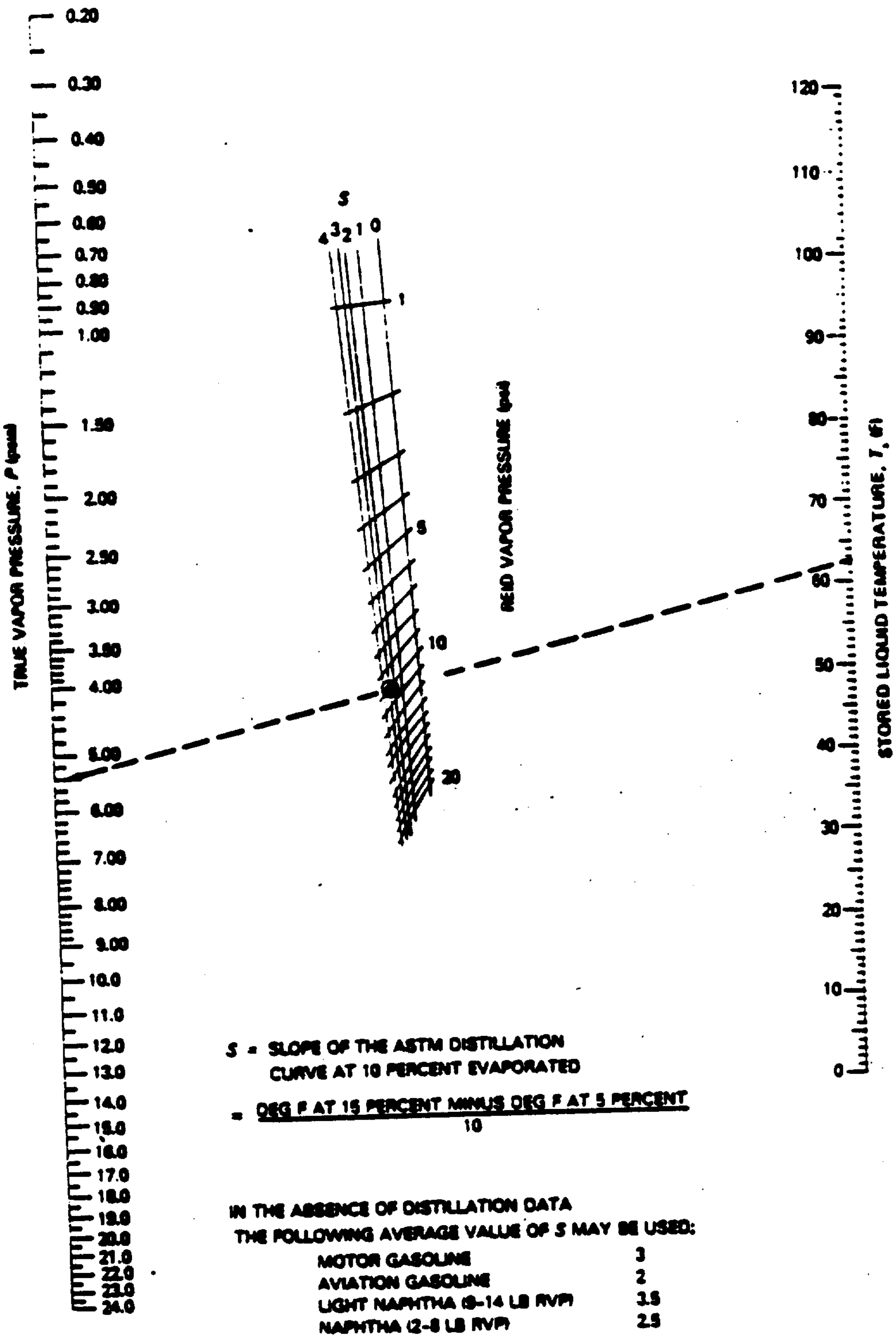


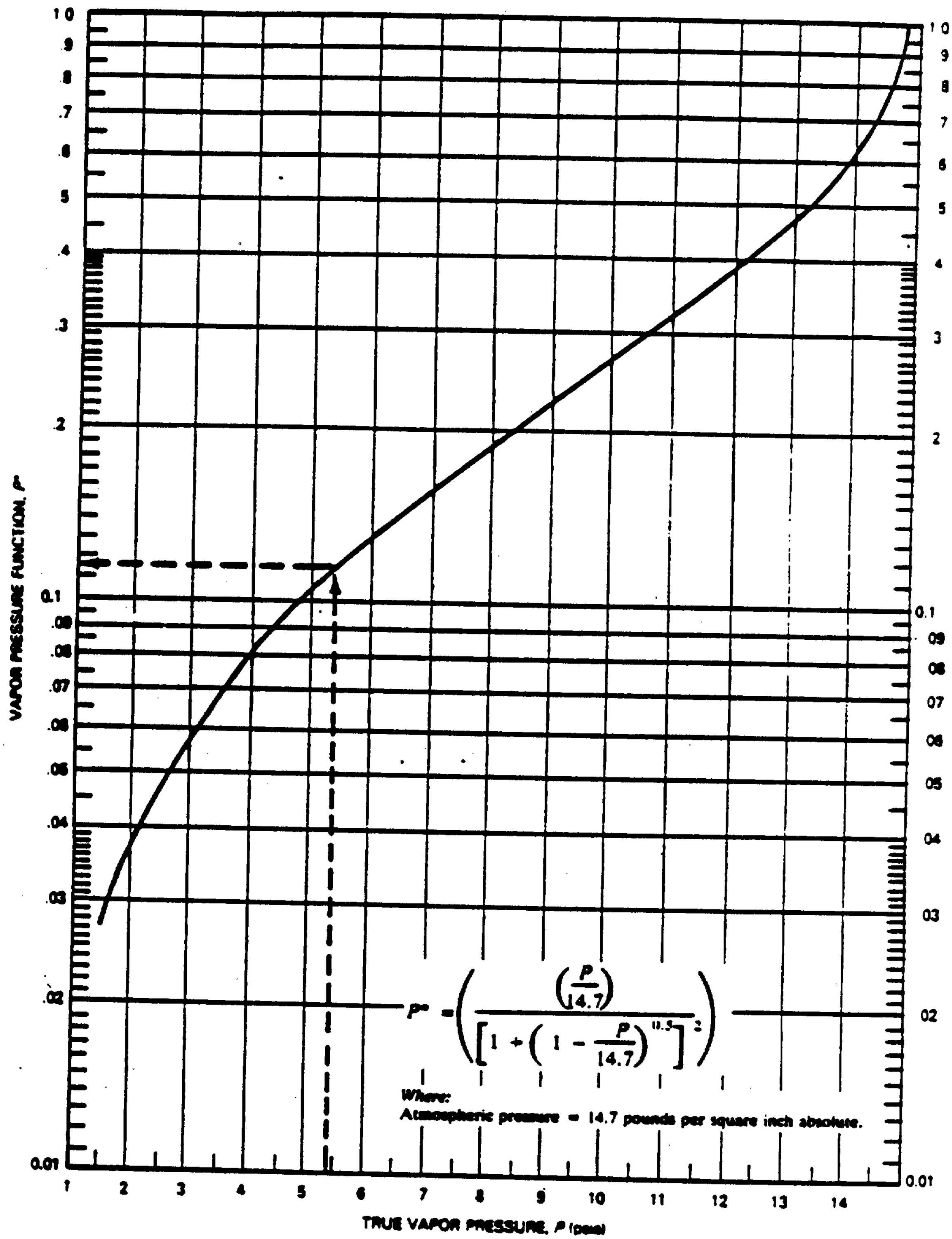
Figure A-3. True vapor pressure (P) of crude oils (2-15 psi RVP).



NOTE: Dashed line illustrates sample problem for RVP = 10 pounds per square inch, gasoline (S = 3), and T_s = 62.5 F

SOURCE: Nomograph drawn from the data of the National Bureau of Standards.

Figure A-4. True vapor pressure (P) of refined petroleum liquids like gasoline and naphthas (1-20 psi RVP).



NOTE: Dashed line illustrates sample problem for P = 5.4 pounds per square inch absolute.

Figure A-5. Vapor pressure function (P*).

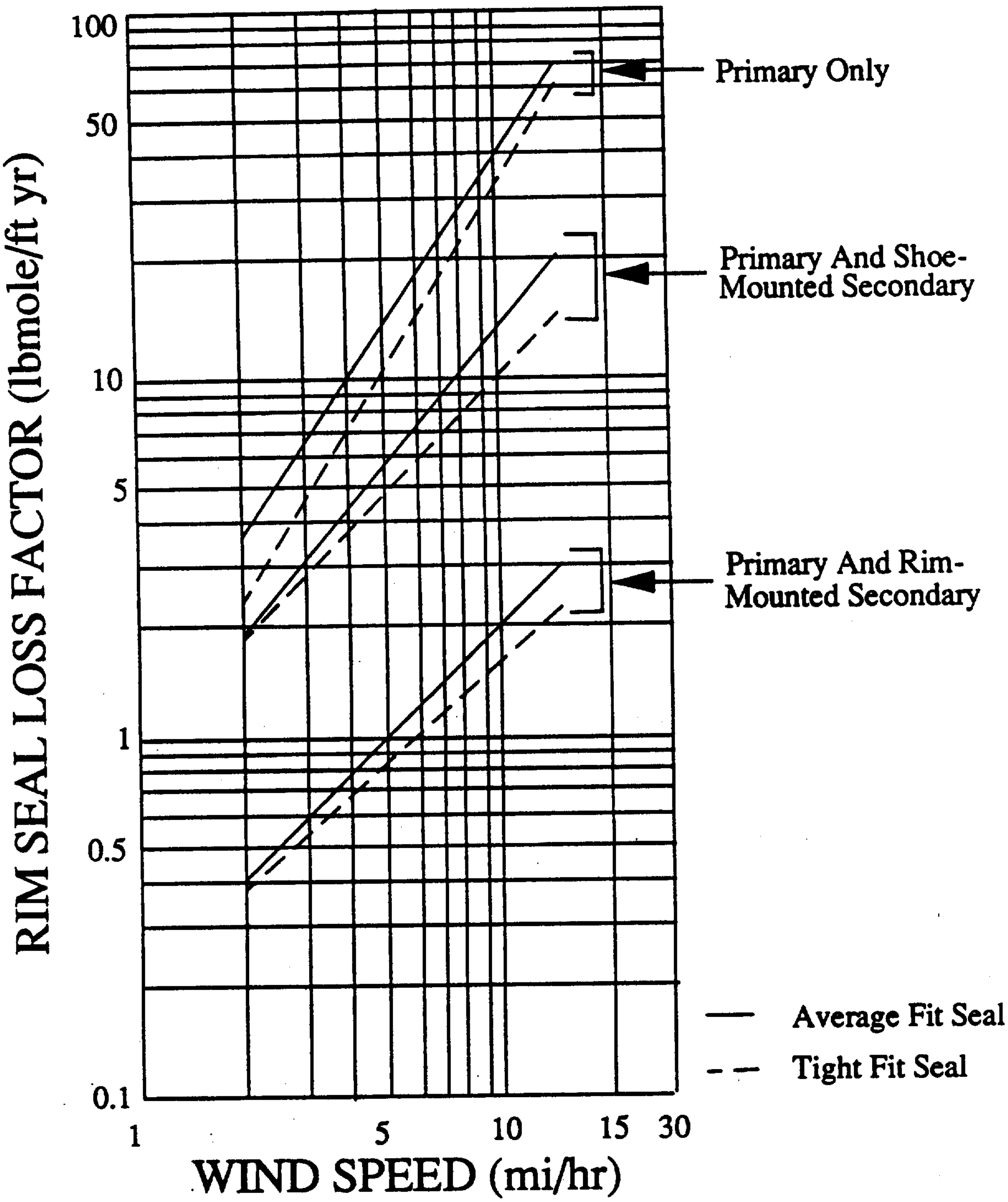


Figure A-6. Rim seal loss factor for an external floating roof welded tank with a mechanical shoe primary seal.

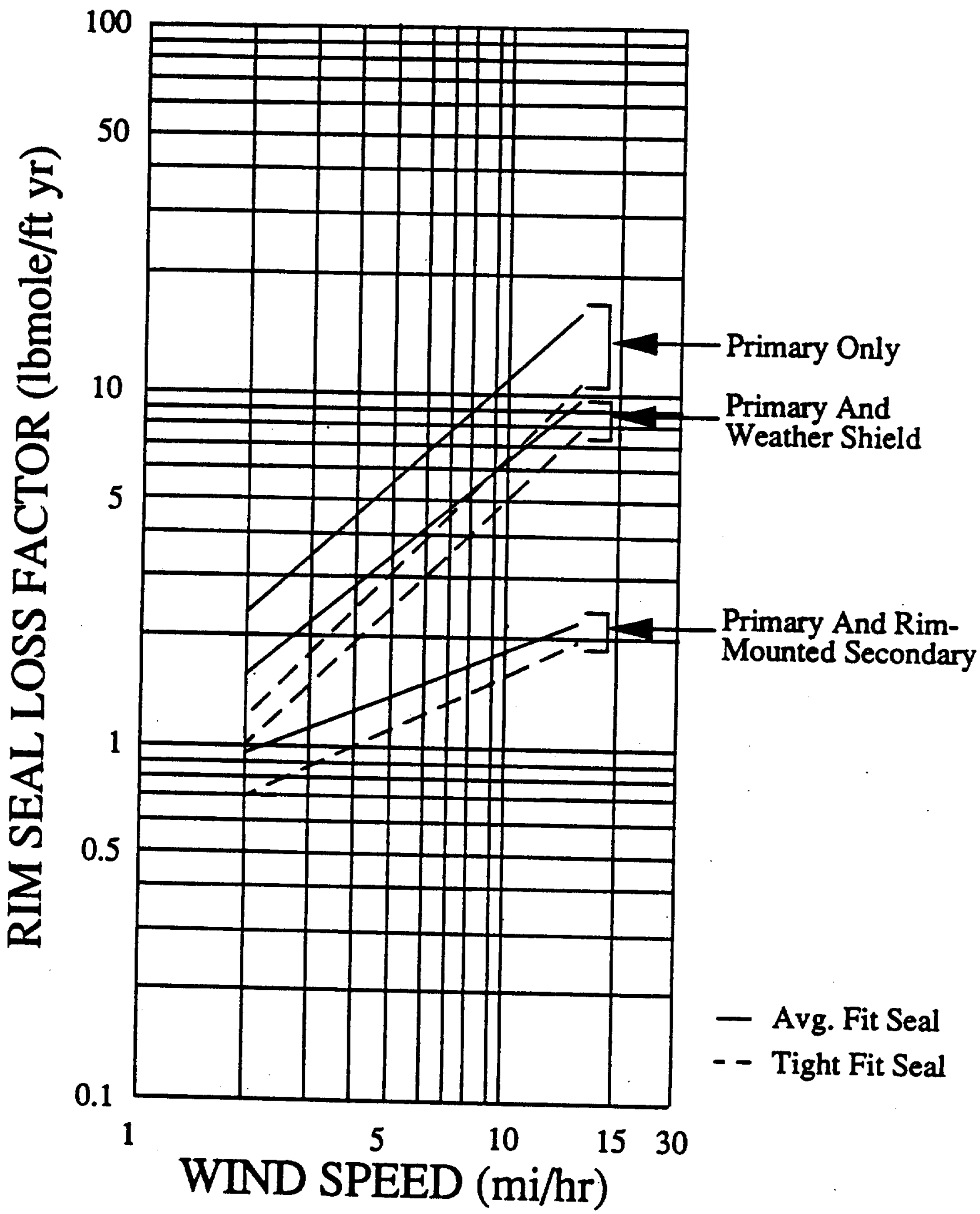


Figure A-7. Rim seal loss factor for an external floating roof welded tank with a liquid-mounted resilient filled primary seal.

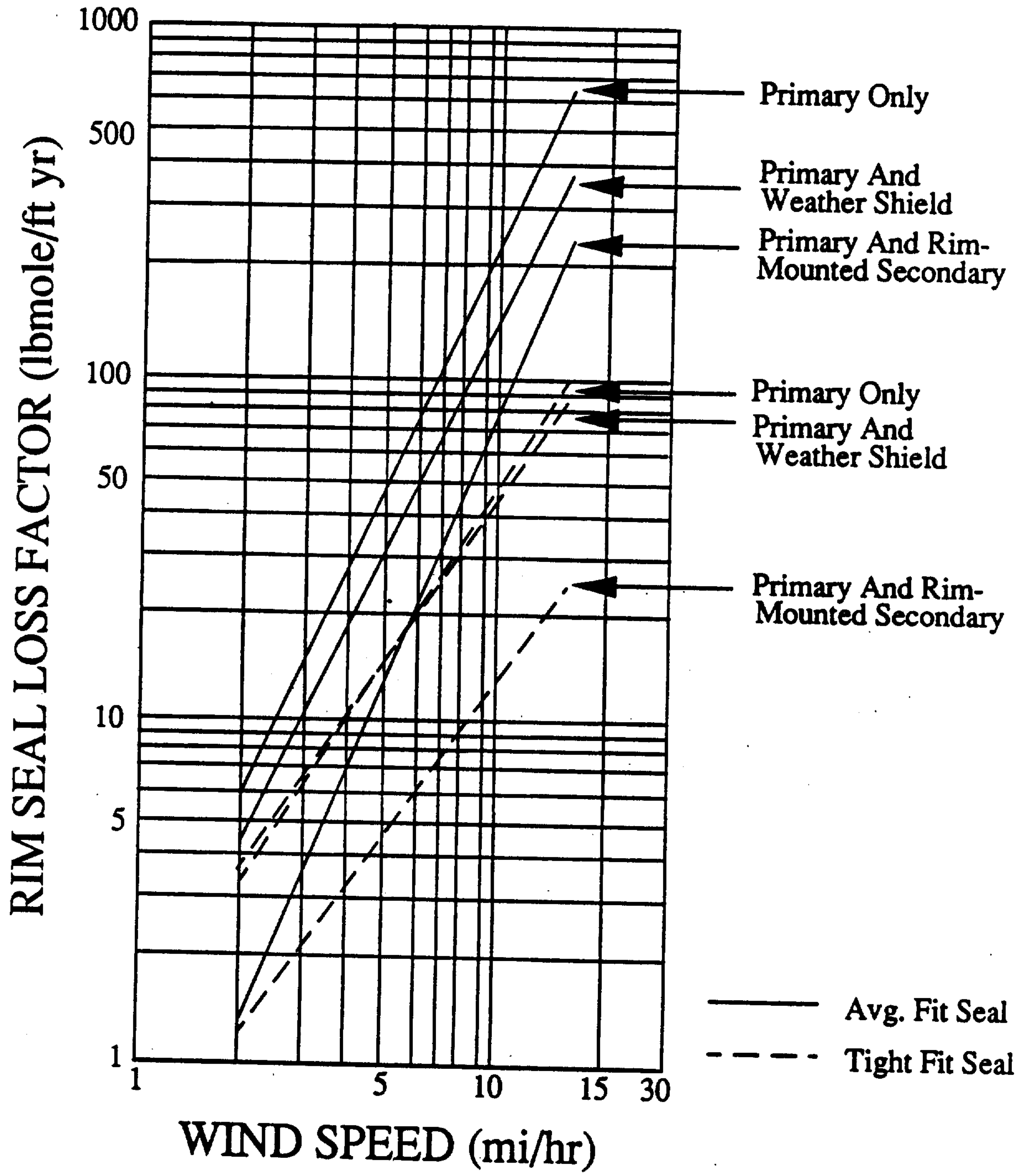


Figure A-8. Rim seal loss factor for an external floating roof welded tank with a vapor-mounted resilient filled primary seal.

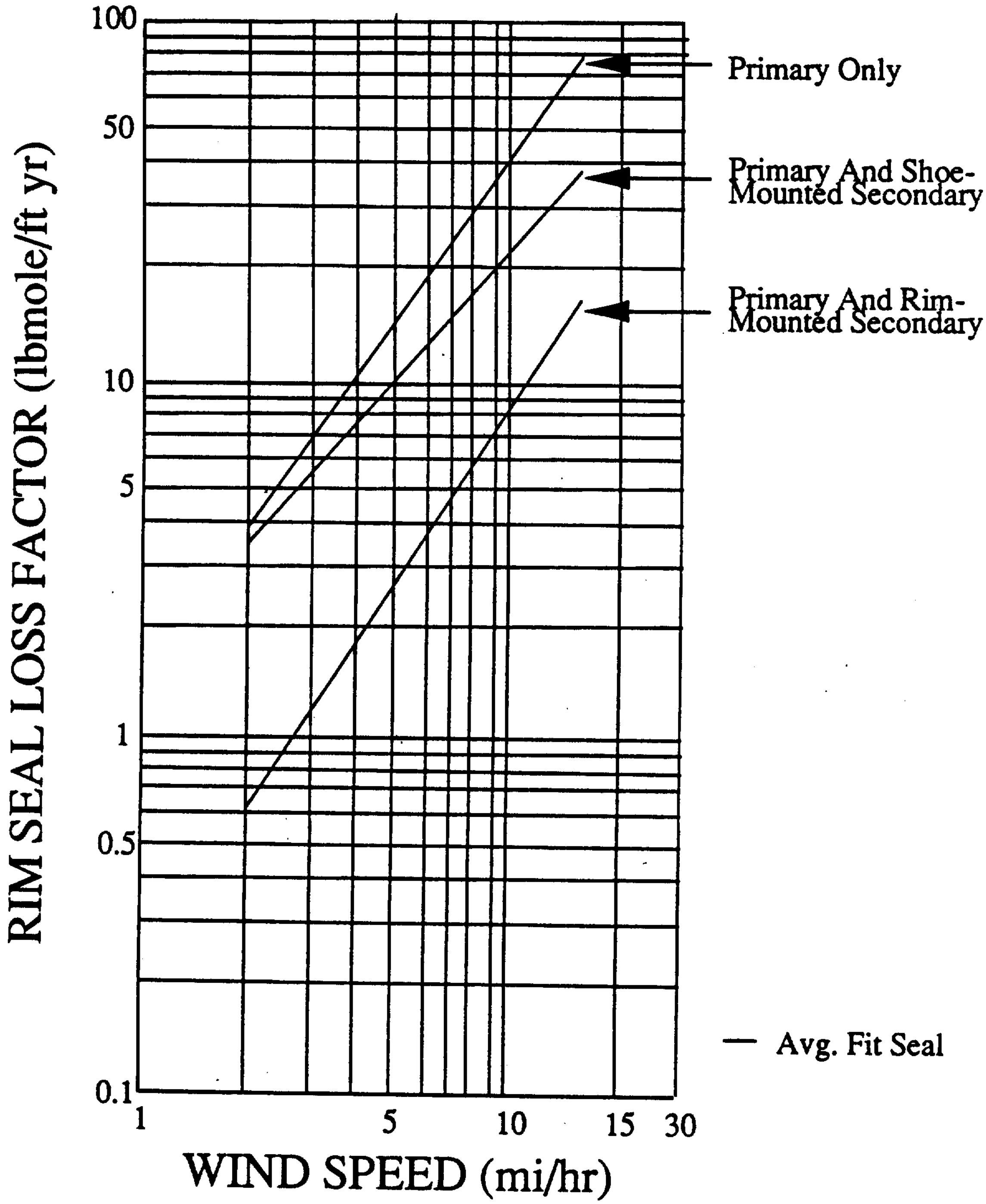


Figure A-9. Rim seal loss factor for an external floating roof riveted tank with a mechanical shoe primary seal.

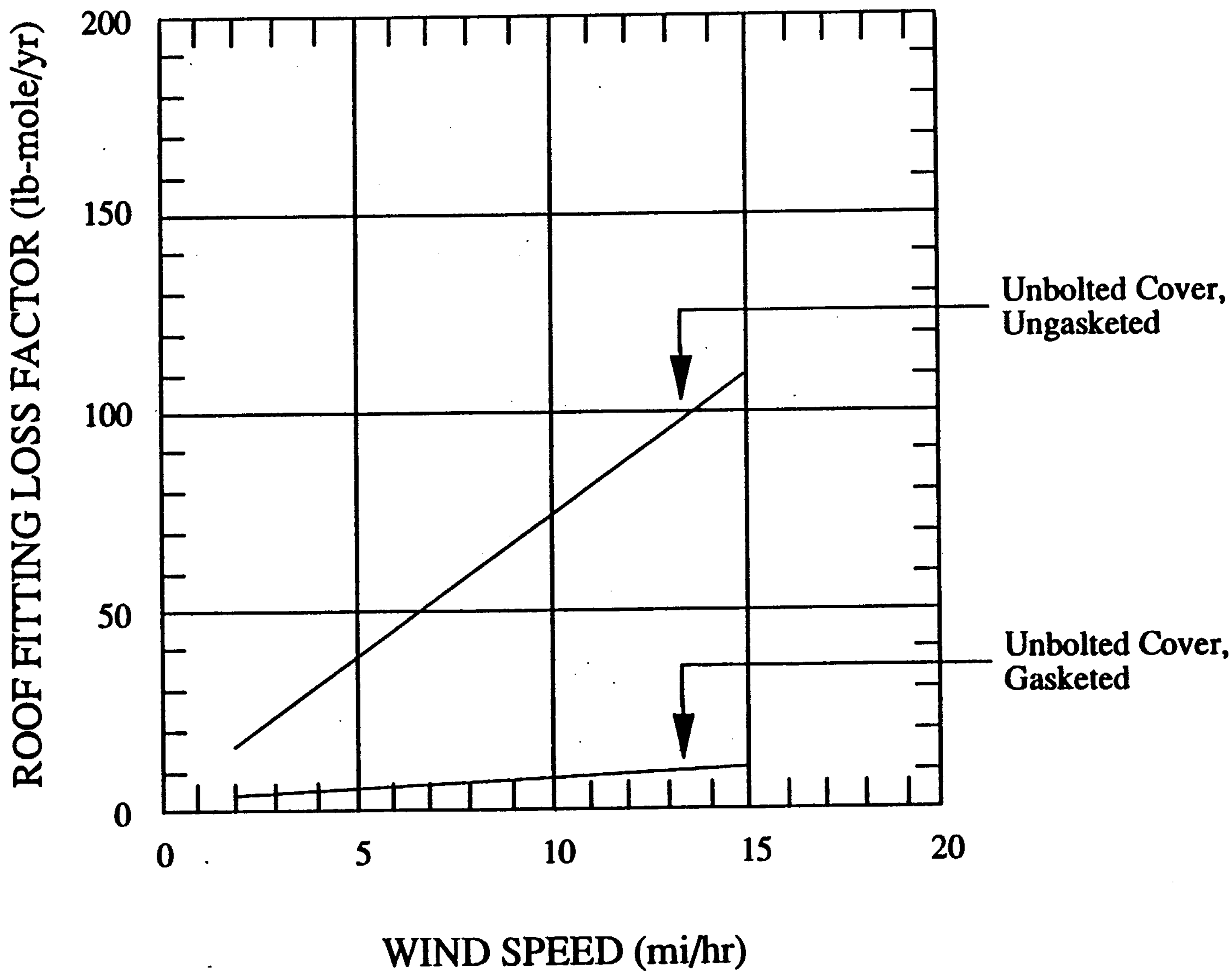


Figure A-10. Roof fitting loss factor for external floating roof access hatches.

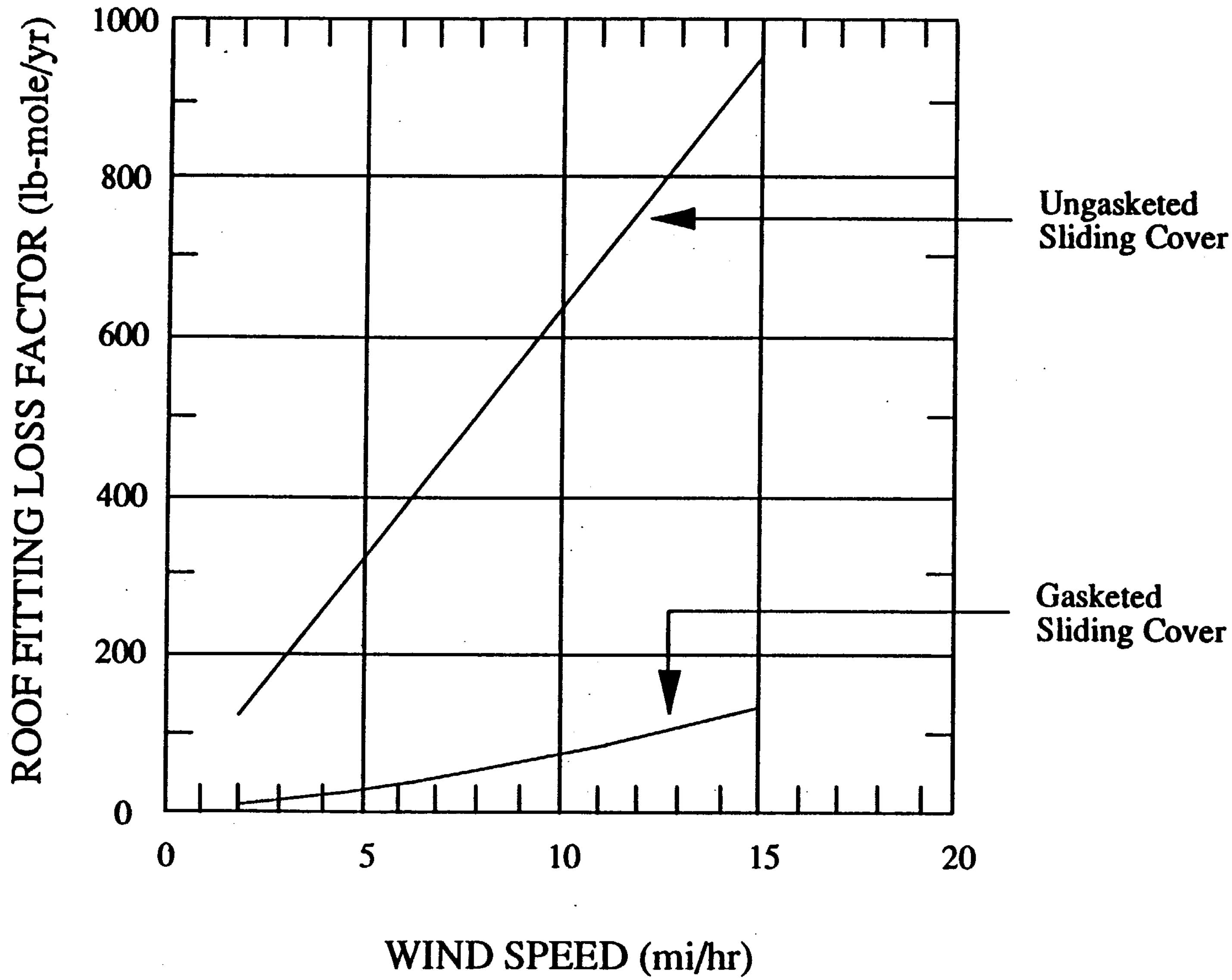


Figure A-11. Roof fitting loss factor for external floating roof unslotted guide pole wells.

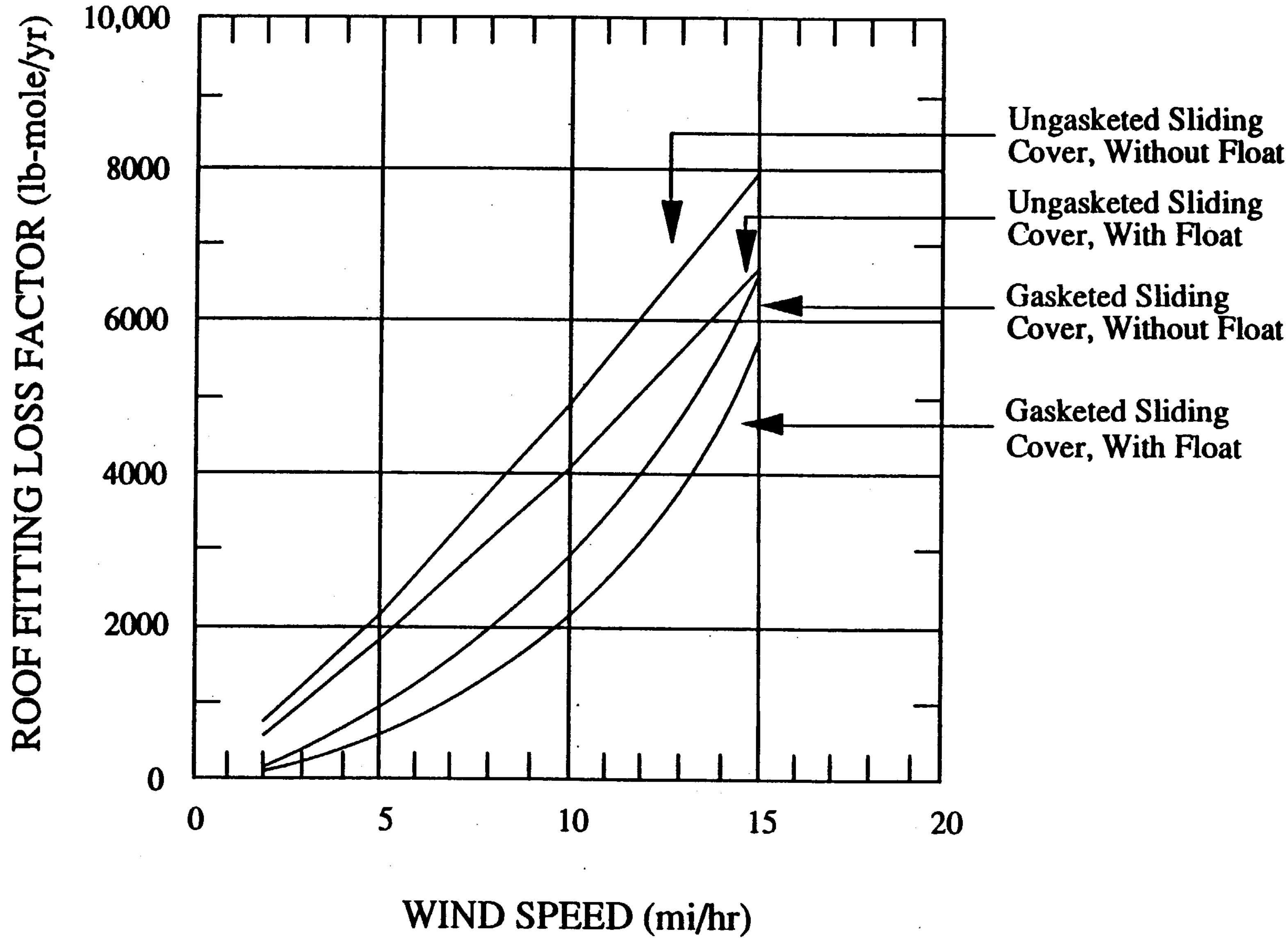


Figure A-12. Roof fitting loss factor for external floating roof slotted guide pole/sample wells.

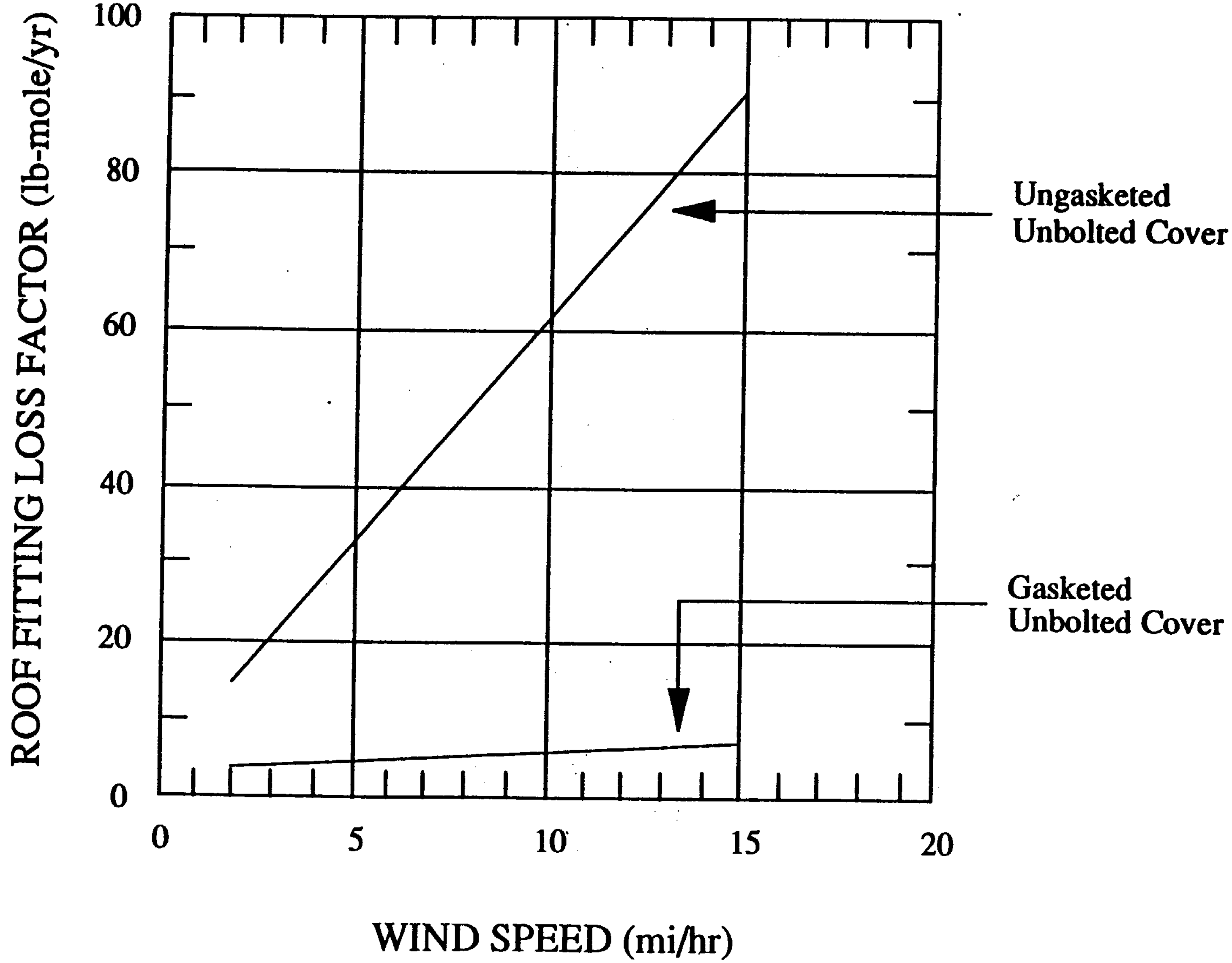


Figure A-13. Roof fitting loss factor for external floating roof gauge float wells.

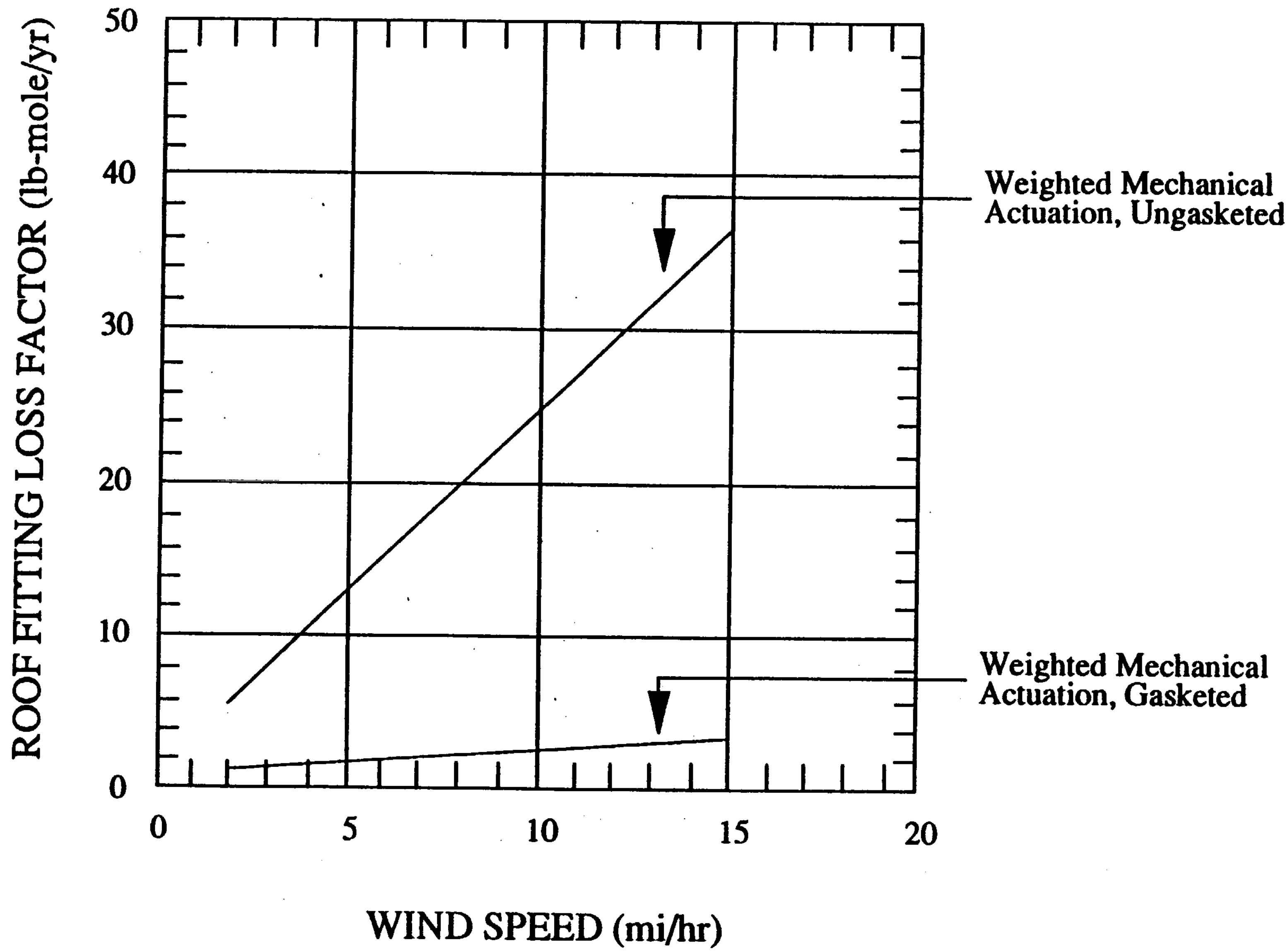


Figure A-14. Roof fitting loss factor for external floating roof gauge hatch/sample wells.

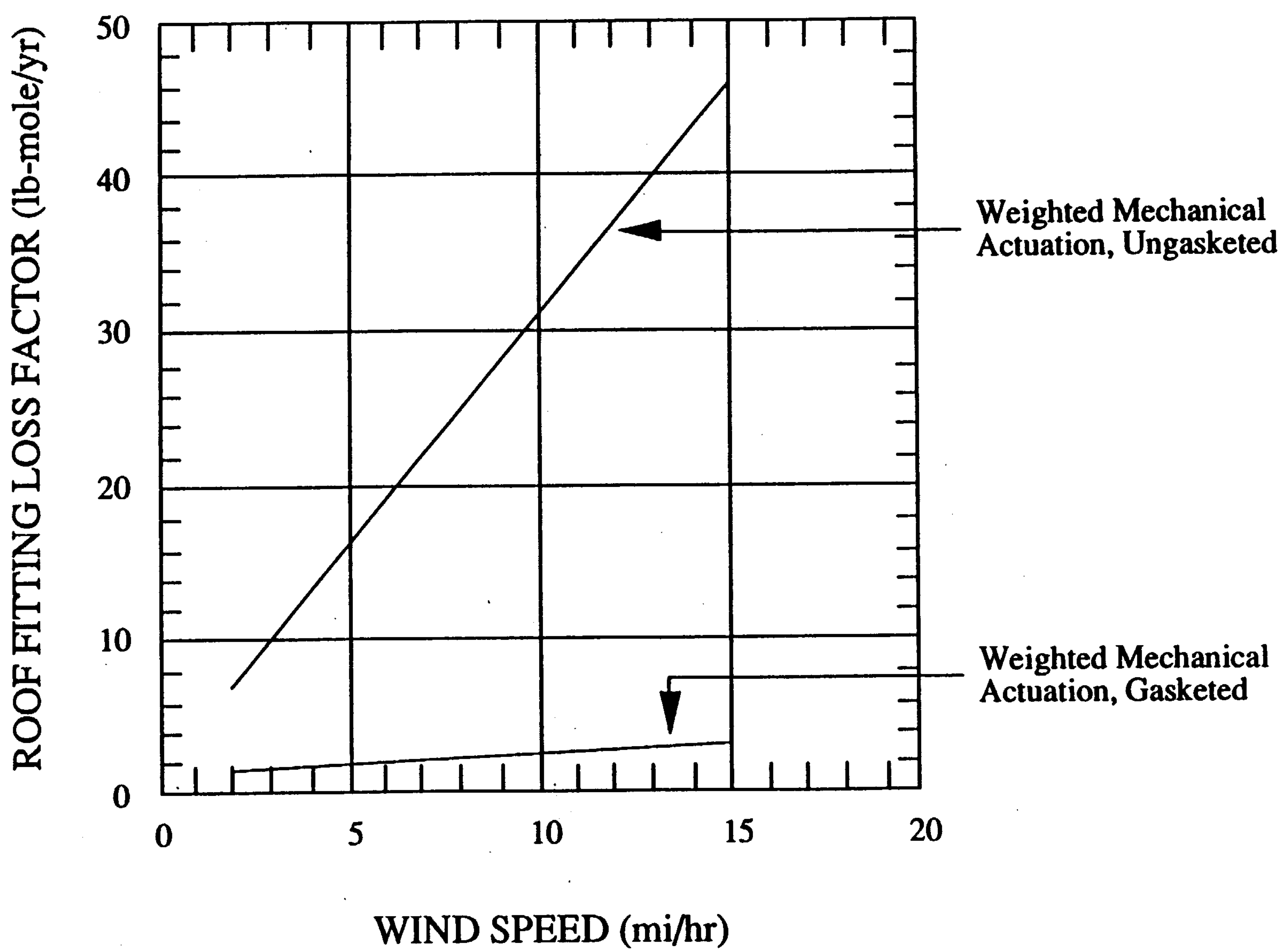


Figure A-15. Roof fitting loss factor for external floating roof vacuum breakers.

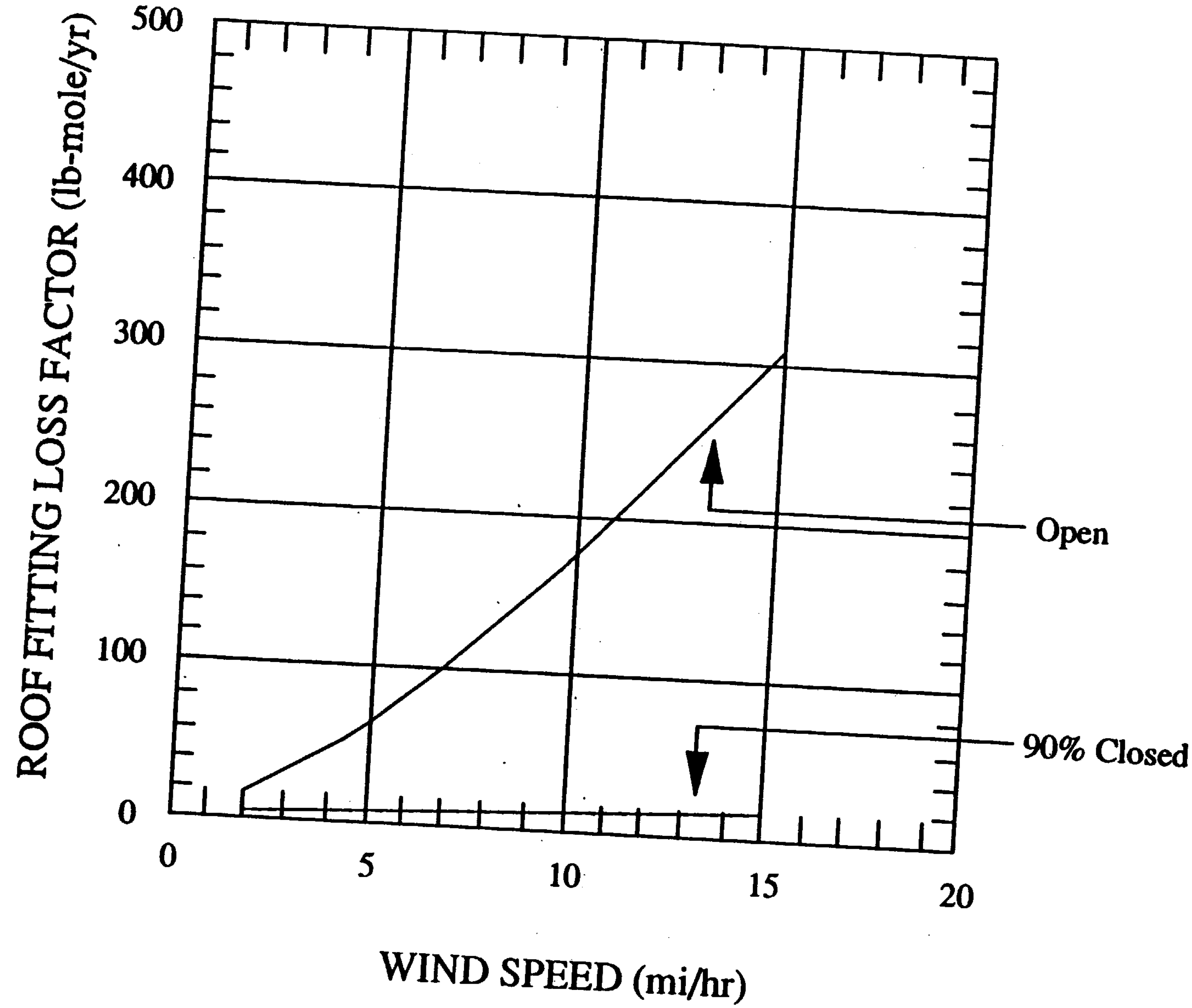


Figure A-16. Roof fitting loss factor for external floating roof drains.

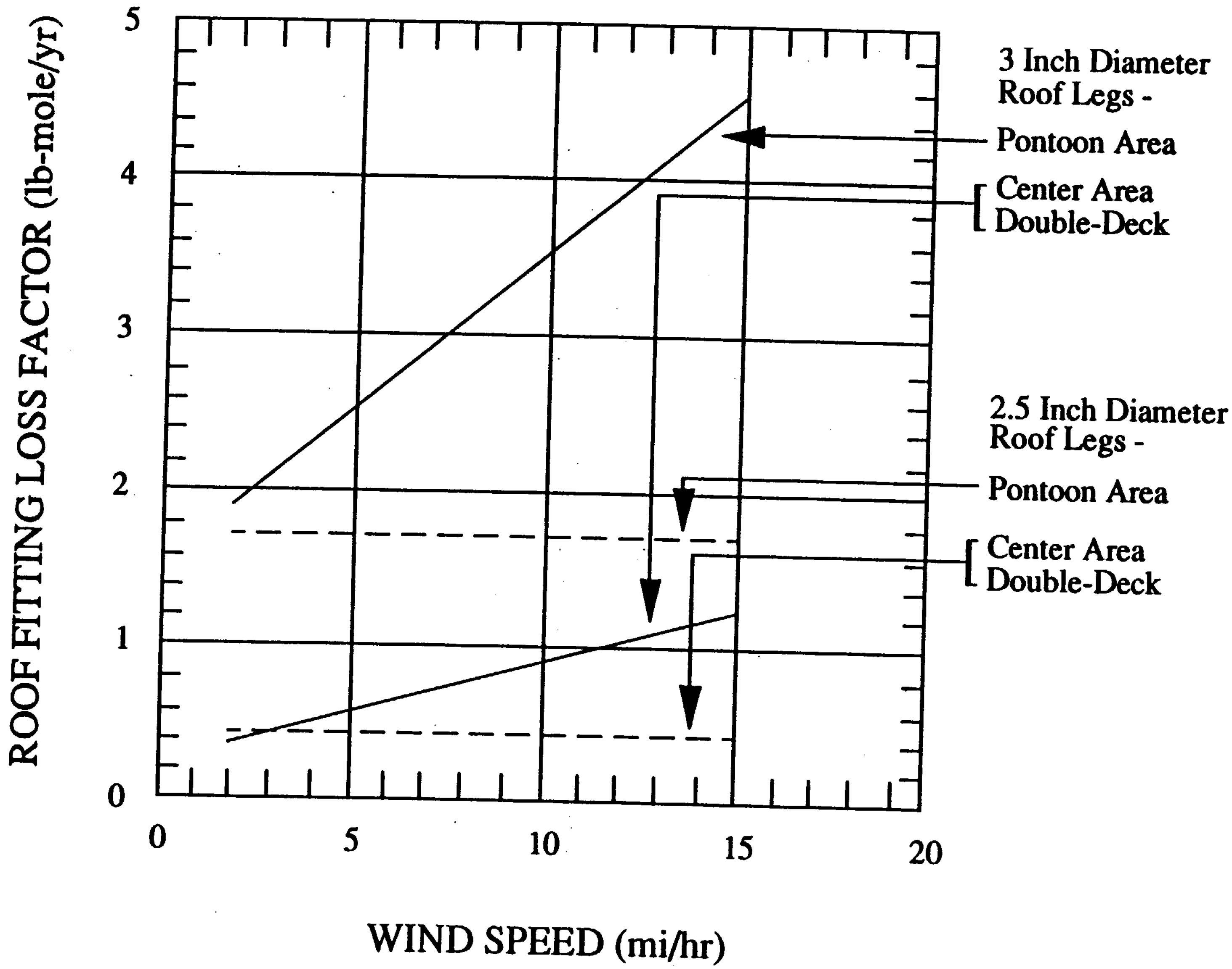


Figure A-17. Roof fitting loss factor for adjustable external floating roof legs.

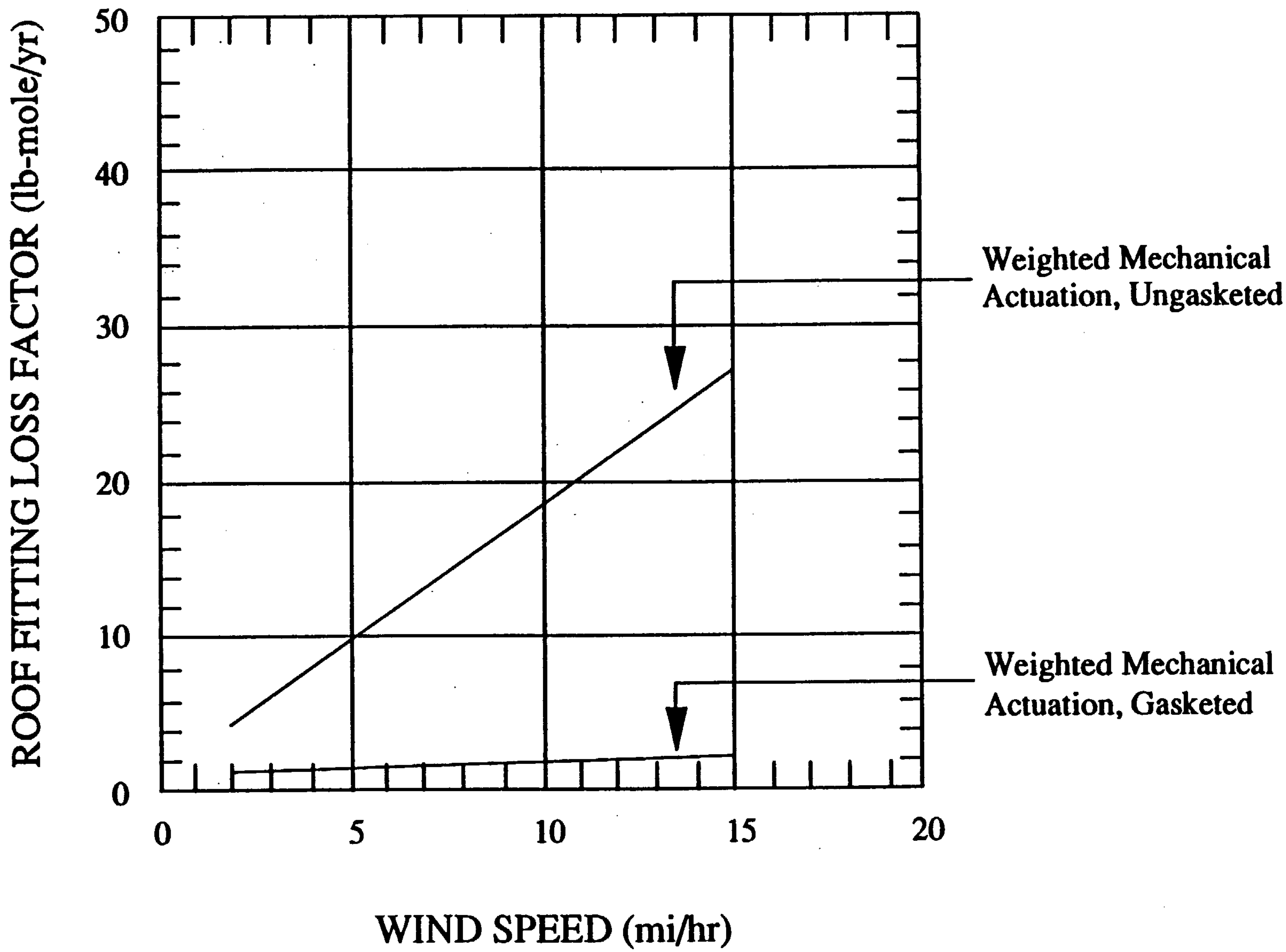


Figure A-18. Roof fitting loss factor for external floating roof rim vents.

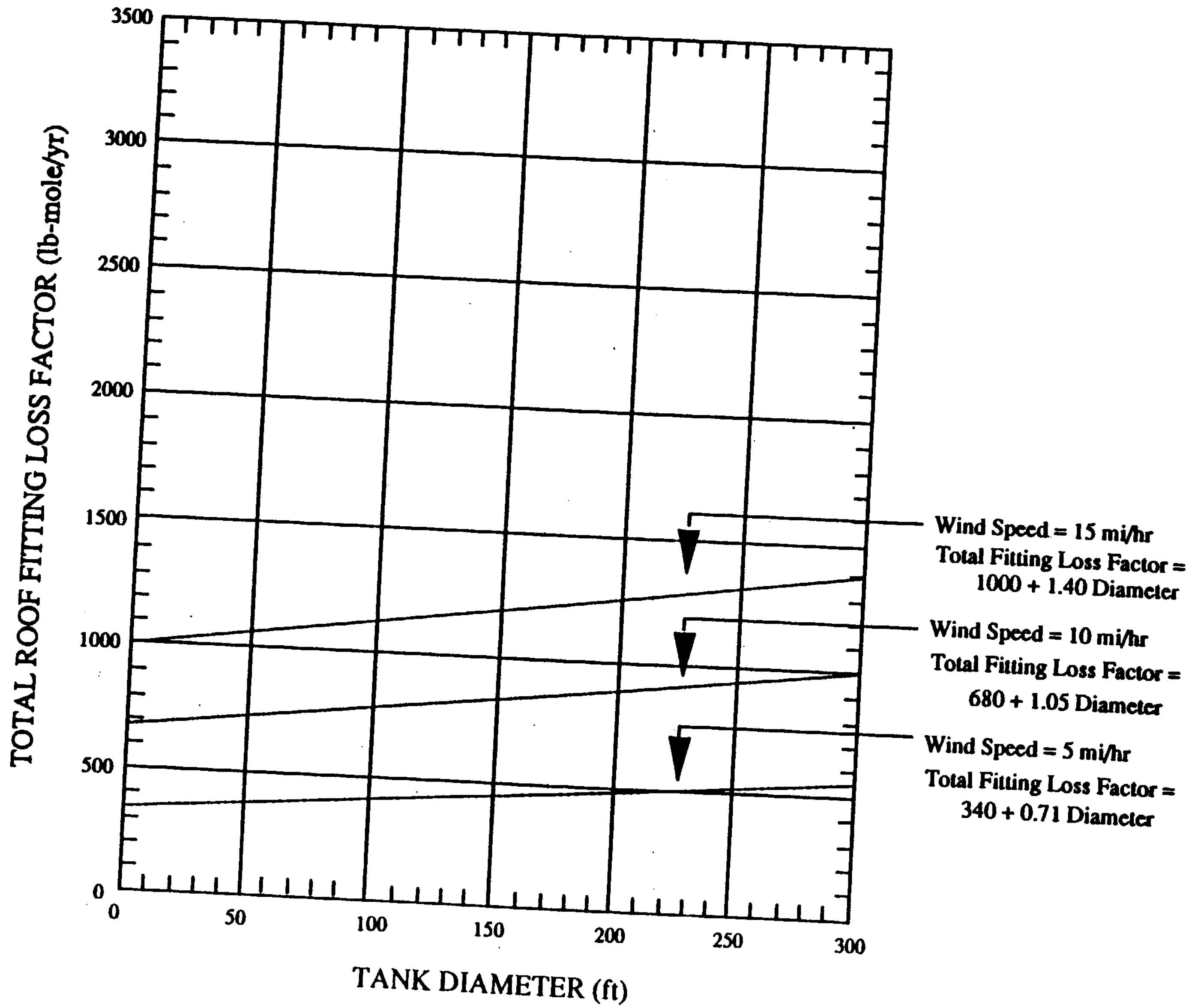


Figure A-19. Total roof fitting loss factor for typical roof fittings on pontoon floating roofs.

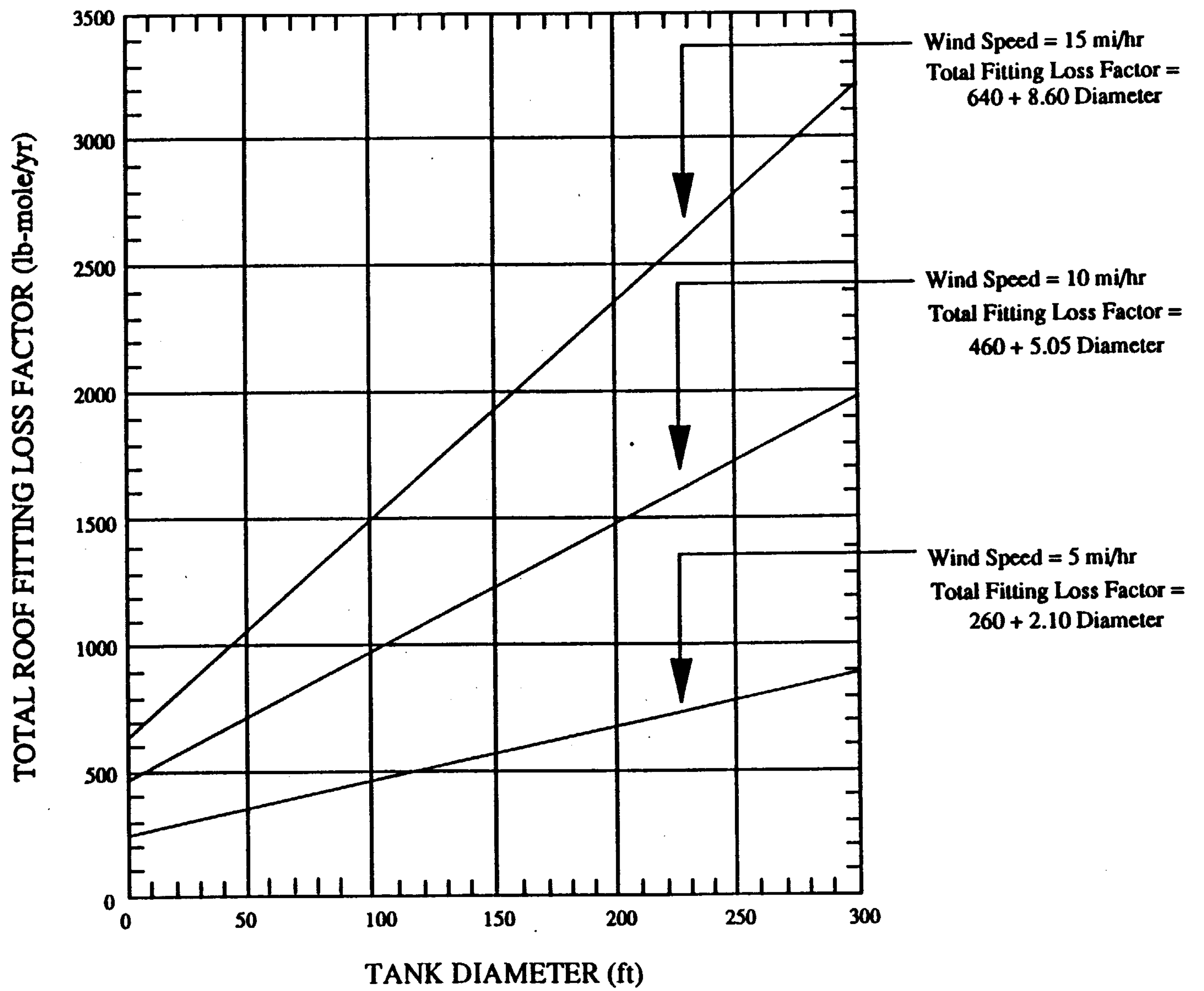
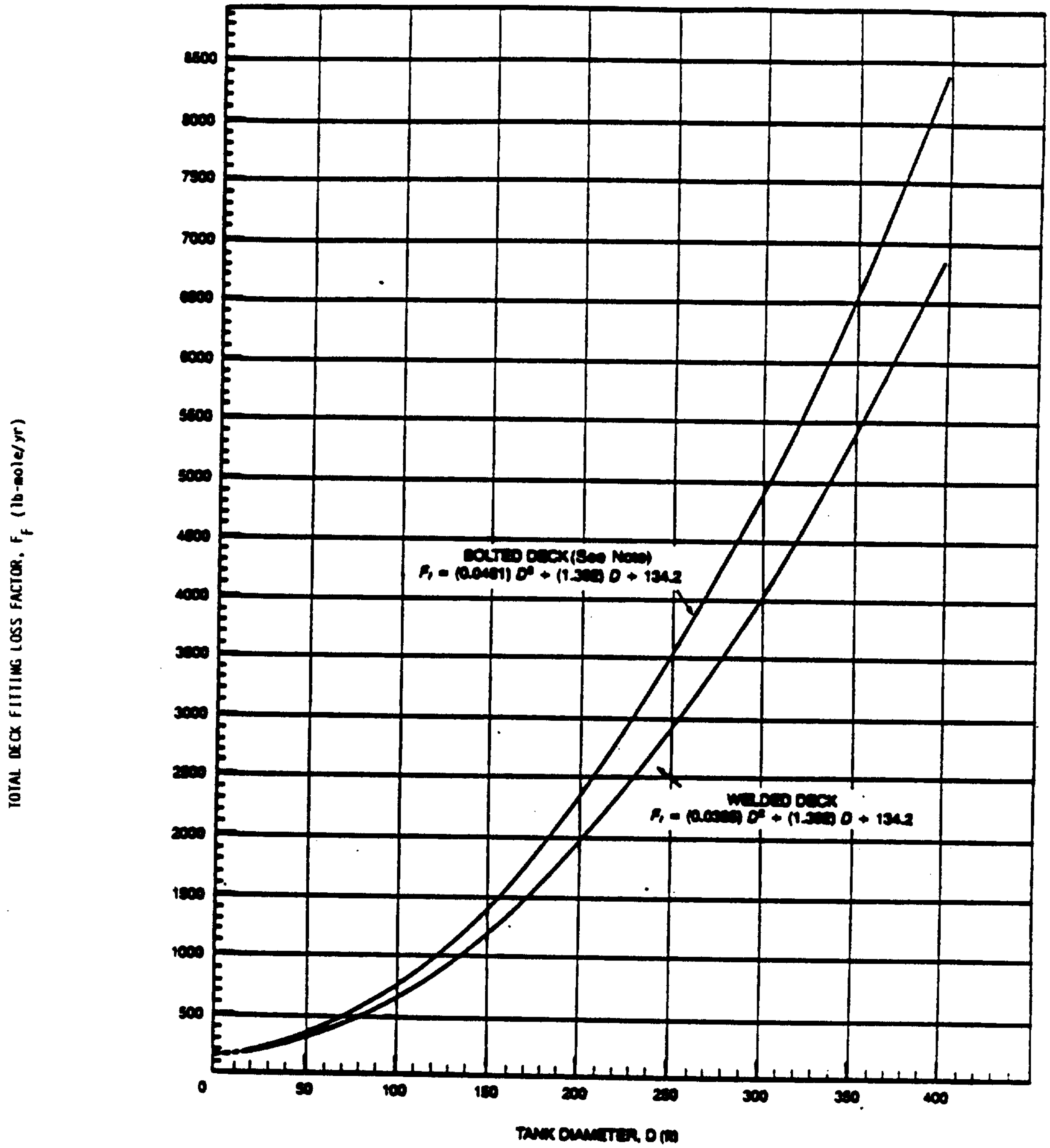


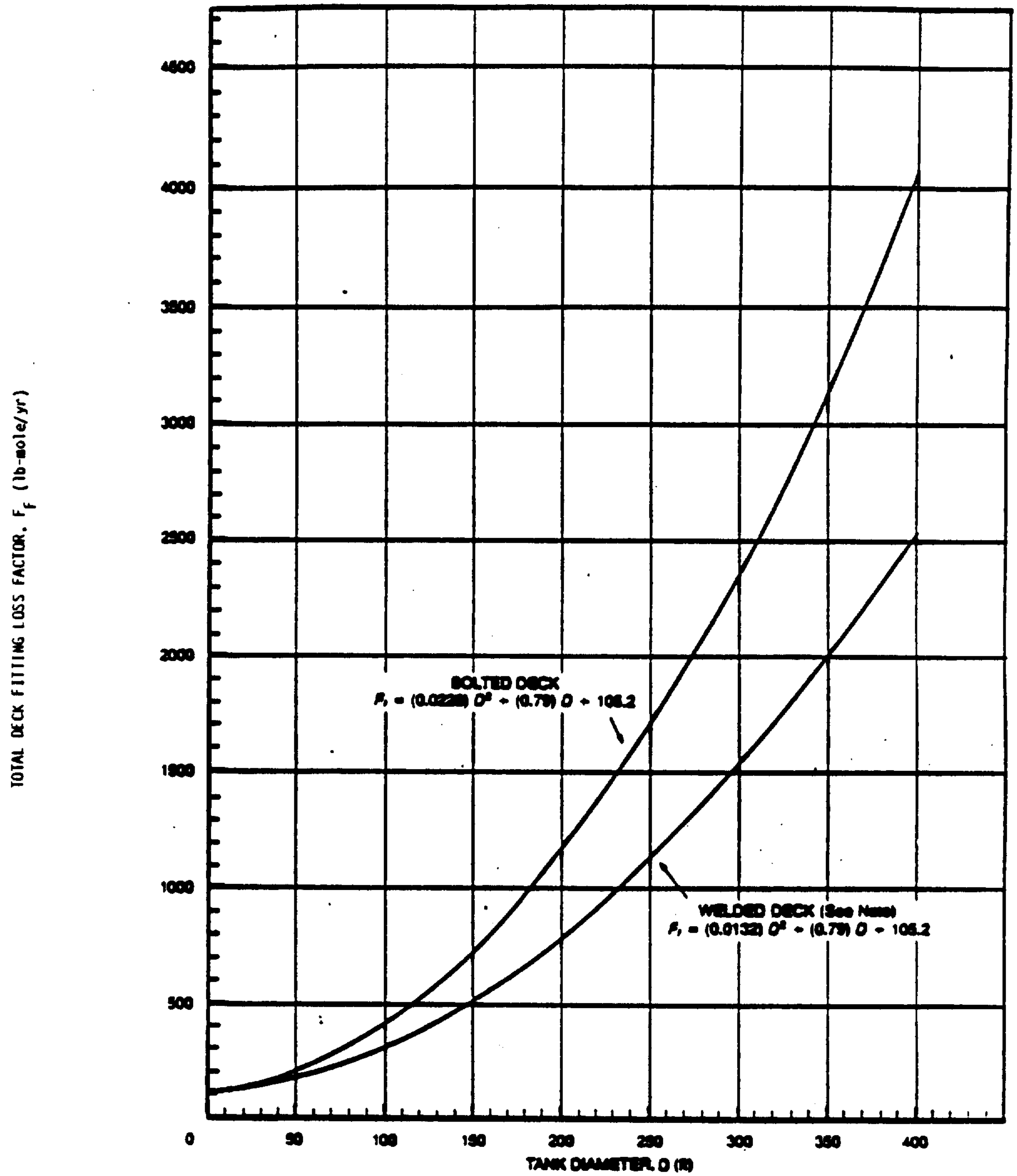
Figure A-20. Total roof fitting loss factor for typical roof fittings on double-deck floating roofs.



3.sis: Fittings include: (1) access hatch, with ungasketed, unbolted cover; (2) built-up column wells, with ungasketed, sliding cover; (3) adjustable deck legs; (4) gauge float well, with ungasketed, unbolted cover; (5) ladder well, with ungasketed sliding cover; (6) sample well, with slit fabric seal (10 percent open area); (7) 1-inch diameter stub drains (only on bolted deck); and (8) vacuum breaker, with gasketed weighted mechanical actuation. This basis was derived from a survey of users and manufacturers. Other fittings may be typically used within particular companies or organizations to reflect standards and/or specifications of that group.

Note: If no specific information is available, assume bolted decks are the most common/typical type currently in use in tanks with column-supported fixed roofs.

Figure A-21. Approximated total deck fitting loss factors (F_F) for typical fittings in tanks with column supported fixed roofs and either a bolted deck or a welded deck. (This figure is used only when tank specific data on the number and kind of deck fittings are unavailable.)



BASIS: Fittings include: (1) access hatch, with ungasketed, unbolted cover; (2) adjustable deck legs; (3) gauge float well, with ungasketed, unbolted cover; (4) sample well, with slit fabric seal (10 percent open area); (5) 1-inch diameter stub drains (only on bolted deck); and (6) vacuum breaker, with gasketed weighted mechanical actuation. This basis was derived from a survey of users and manufacturers. Other fittings may be typically used within particular companies or organizations to reflect standards and/or specifications of that group.

NOTES: If no specific information is available, assume welded decks are the most common/typical type currently in use in tanks with self-supporting fixed roofs.

Figure A-22. Approximated total deck fitting loss factors (F_F) for typical deck fittings in tanks with self-supported fixed roofs and either a bolted deck or a welded deck. (This figure is to be used only when tank specific data on the number and kind of deck fittings are unavailable.)

TABLE A-1. PAINT FACTORS (F_p) FOR FIXED ROOF TANKS

Tank color		Paint factors (F_p) Paint condition	
Roof	Shell	Good	Poor
White	White	1.00	1.15
Aluminum (specular)	White	1.04	1.18
White	Aluminum (specular)	1.16	1.24
Aluminum (specular)	Aluminum (specular)	1.20	1.29
White	Aluminum (diffuse)	1.30	1.38
Aluminum (diffuse)	Aluminum (diffuse)	1.39	1.46
White	Gray	1.30	1.38
Light gray	Light gray	1.33	1.44[a]
Medium gray	Medium gray	1.40	1.58[a]

[a]Estimated from the ratios of the seven preceding paint factors.

TABLE A-2. PHYSICAL PROPERTIES OF COMMON AIR SUBSTANCES [a]

Organic liquid	Vapor molecular weight at 60°F	Liquid density, lb/gal at 60°F	Condensed vapor density, lb/gal at 60°F	True vapor pressure in psia at: 40°F	50°F	60°F	70°F	80°F	90°F	100°F
Petroleum liquids[b]										
Gasoline RVP 13	62	5.6	4.9	4.7	5.7	6.9	8.3	9.9	11.7	13.8
Gasoline RVP 10	66	5.6	5.1	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gasoline RVP 7	68	5.6	5.2	2.3	2.9	3.5	4.3	5.2	6.2	7.4
Crude oil RVP 5	50	7.1	4.5	1.8	2.3	2.8	3.4	4.0	4.8	5.7
Jet Naphtha (JP-4)	80	6.4	5.4	0.8	1.0	1.3	1.6	1.9	2.4	2.7
Jet kerosene	130	7.0	6.1	0.0041	0.0060	0.0085	0.011	0.015	0.021	0.029
Distillate fuel No. 2	130	7.1	6.1	0.0031	0.0045	0.0074	0.0090	0.012	0.016	0.022
Residual oil No. 6	190	7.9	6.4	0.00002	0.00003	0.00004	0.00006	0.00009	0.00013	0.00019
Volatile organic liquids										
Acetone	58.1	6.6	6.6	1.7	2.2	2.9	3.7	4.7	5.9	7.3
Acetonitrile	41.1	6.6	6.6	0.6	0.8	1.1	1.4	1.9	2.5	3.1
Acrylonitrile	53.1	6.8	6.8	0.8	1.0	1.4	1.8	2.4	3.1	4.0
Allyl alcohol	58.1	7.1	7.1	0.1	0.2	0.3	0.4	0.5	0.7	1.0
Allyl chloride	76.5	7.9	7.9	3.0	3.8	4.8	6.0	7.4	9.1	11.0
Ammonium hydroxide 28.8 percent solution	35.1	7.5	7.5	5.1	6.6	8.5	10.8	13.5	16.8	20.7
Benzene	78.1	7.4	7.4	0.6	0.9	1.2	1.5	2.0	2.6	3.3
n-Butyl chloride	92.6	7.4	7.4	0.7	1.0	1.3	1.7	2.2	2.7	3.5
Carbon disulfide	76.1	10.6	10.6	3.0	3.9	4.8	6.0	7.4	9.2	11.2
Carbon tetrachloride	153.8	13.4	13.4	0.8	1.1	1.4	1.8	2.3	3.0	3.8
Chloroform	119.4	12.5	12.5	1.5	1.9	2.5	3.2	4.1	5.2	6.3
Chloroprene	88.5	8.0	8.0	1.8	2.3	2.9	3.7	4.6	5.7	7.0
Cyclohexane	84.2	6.5	6.5	0.7	0.9	1.2	1.6	2.1	2.6	3.2
Cyclopentane	70.1	6.2	6.2	2.5	3.3	4.2	5.2	6.5	8.1	9.7
1,1-Dichloroethane[c]	99.0	9.9	9.9	1.7	2.2	2.9	3.7	4.7	5.9	7.4
1,2-Dichloroethane[c]	99.0	10.5	10.5	0.6	0.8	1.0	1.4	1.7	2.2	2.8
cis-1,2-Dichloroethylene	97.0	10.8	10.8	1.5	2.0	2.7	3.5	4.4	5.6	6.8
trans-1,2-Dichloroethylene	97.0	10.5	10.5	2.6	3.4	4.4	5.5	6.8	8.3	10.0
Diethyl ether	74.1	6.0	6.0	4.2	5.7	7.0	8.7	10.4	13.3	Boils
Diethylamine	73.1	5.9	5.9	1.6	2.0	2.9	3.9	4.9	6.1	7.5
Diisopropyl ether	102.2	6.1	6.1	1.2	1.6	2.1	2.7	3.5	4.3	5.3
1,4-Dioxane	88.1	8.7	8.7	0.2	0.3	0.4	0.6	0.8	1.1	1.5
Dipropyl ether	102.2	6.3	6.3	0.4	0.6	0.8	1.1	1.4	1.9	2.3
Ethyl acetate	88.1	7.6	7.6	0.6	0.8	1.1	1.5	1.9	2.5	3.2
Ethyl acrylate	100.1	7.8	7.8	0.2	0.3	0.4	0.6	0.8	1.1	1.5
Ethyl alcohol	46.1	6.6	6.6	0.2	0.4	0.6	0.9	1.2	1.7	2.3
Freon 11	137.4	12.5	12.5	7.0	8.8	10.9	13.4	16.3	19.7	23.6
n-Heptane	100.2	5.7	5.7	0.3	0.4	0.5	0.7	1.0	1.2	1.6
Hexane[c]	86.2	5.5	5.5	1.1	1.5	1.9	2.4	3.1	3.9	4.9
Isobutyl alcohol	74.1	6.7	6.7	0.06	0.1	0.1	0.2	0.3	0.4	0.5

(continued)

TABLE A-2. (continued)

Organic liquid	Vapor molecular weight at 60°F	Liquid density, lb/gal at 60°F	Condensed vapor density, lb/gal at 60°F	True vapor pressure in psia at: 40°F						
				40°F	50°F	60°F	70°F	80°F	90°F	100°F
Isopropyl alcohol	60.1	6.6	6.6	0.2	0.3	0.6	0.7	0.9	1.3	1.8
Methyl acetate	74.1	7.8	7.8	1.5	2.0	2.7	3.7	4.7	5.8	7.0
Methyl acrylate	86.1	8.0	8.0	0.6	0.8	1.0	1.4	1.8	2.4	3.1
Methyl alcohol	32.0	6.6	6.6	0.7	1.0	1.4	2.0	2.6	3.5	4.5
Methylene chloride	84.9	11.1	11.1	3.1	4.3	5.4	6.8	8.7	10.3	13.3
Methyl cyclopentane	84.1	6.3	6.3	0.9	1.2	1.6	2.2	2.9	3.6	4.5
Methyl ethyl ketone	72.1	6.7	6.7	0.7	0.9	1.2	1.5	2.1	2.7	3.3
Methylmethacrylate	100	7.9	7.9	0.1	0.2	0.3	0.6	0.8	1.1	1.4
Methyl propyl ether	74.1	6.2	6.2	3.7	4.7	6.1	7.1	9.4	11.6	13.7
n-Pentane[c]	72.2	5.3	5.3	4.3	5.5	6.8	8.5	10.5	12.8	15.6
n-Propylamine	59.1	6.0	6.0	2.5	3.2	4.2	5.3	6.5	8.0	9.6
Propyl chloride[c]	78.5	[d]	[d]	2.8	3.5	4.5	5.6	7.0	8.7	10.6
Tertbutyl alcohol	74.1	6.6	[d]	0.2	0.3	0.4	0.6	0.9	1.2	1.7
1,1,1-Trichloroethane	133.4	11.2	11.2	0.9	1.2	1.6	2.0	2.6	3.3	4.2
Trichloroethylene	131.4	12.3	12.3	0.5	0.7	0.9	1.2	1.5	2.0	2.0
Toluene	92.1	7.3	7.3	0.2	0.2	0.3	0.4	0.6	0.8	1.0
Vinylacetate	86.1	7.8	7.8	0.7	1.0	1.3	1.7	2.3	3.1	4.0
Vinyledene chloride	96.5	10.4	10.4	5.0	6.3	7.9	9.8	11.8	15.3	23.2

[a] Before using this table to locate vapor pressures, make sure that the temperature has been corrected for tank color using Table A-3.
[b] RVP = Reid vapor pressure.
[c] Vapor pressures calculated from pages D-212 through D-215 of "Handbook of Physics and Chemistry," 67th Edition.
[d] Data unavailable.

TABLE A-3. AVERAGE ANNUAL STORAGE TEMPERATURE (T_S) AS A FUNCTION OF TANK PAINT COLOR

Tank color	Average annual storage temperature, T_S
White	T_A+0[a]
Aluminum	$T_A+2.5$
Gray	$T_A+3.5$
Black	$T_A+5.0$

[a]T_A is the average annual ambient temperature in degrees Fahrenheit.

TABLE A-4. AVERAGE ANNUAL AMBIENT TEMPERATURE (T_a, °F) FOR SELECTED U.S. LOCATIONS

Birmingham, Ala.	62.0
Huntsville, Ala.	60.6
Mobile, Ala.	67.5
Montgomery, Ala.	64.9
Anchorage, Alaska	35.3
Annette, Alaska	45.4
Barrow, Alaska	9.1
Barter Island, Alaska	9.6
Bethel, Alaska	28.4
Bettles, Alaska	21.2
Big Delta, Alaska	27.4
Cold Bay, Alaska	37.9
Fairbanks, Alaska	23.9
Gulkana, Alaska	26.5
Homer, Alaska	36.6
Juneau, Alaska	40.0
King Salmon, Alaska	32.8
Kodiak, Alaska	40.7
Kotzebue, Alaska	20.9
McGrath, Alaska	25.0
Nome, Alaska	25.5
St. Paul Island, Alaska	34.3
Talkeetna, Alaska	32.6
Unalakleet, Alaska	26.4
Valdez, Alaska	38.3
Yakutat, Alaska	38.6
Flagstaff, Ariz.	45.4
Phoenix, Ariz.	71.2
Tucson, Ariz.	68.0
Winslow, Ariz.	54.9
Yuma, Ariz.	73.8
Fort Smith, Ariz.	60.8
Little Rock, Ark.	61.9
North Little Rock, Ark.	61.7
Bakersfield, Calif.	65.5
Bishop, Calif.	56.0
Blue Canyon, Calif.	50.4
Eureka, Calif.	52.0
Fresno, Calif.	62.6
Long Beach, Calif.	63.9
Los Angeles, Calif.--International Airport	62.6
Los Angeles, Calif.	65.3
Mount Shasta, Calif.	49.5
Red Bluff, Calif.	62.9
Sacramento, Calif.	60.6
San Diego, Calif.	63.8
San Francisco, Calif.--International Airport	56.6
San Francisco, Calif.--City	56.8
Santa Barbara, Calif.	58.9
Santa Maria, Calif.	56.8
Stockton, Calif.	61.6
Alasosa, Colo.	41.2
Colorado Springs, Colo.	48.9
Denver, Colo.	50.3
Grand Junction, Colo.	52.7
Pueblo, Colo.	52.8
Bridgeport, Conn.	51.8
Hartford, Conn.	49.8
Wilmington, Del.	54.0
Wash., D.C.-Dulles Airport	53.9
Wash. D.C.-National Airport	57.5
Apalachicola, Fla.	68.2
Daytona Beach, Fla.	70.3
Fort Myers, Fla.	73.9
Gainsville, Fla.	68.6
Jacksonville, Fla.	68.0
Key West, Fla.	77.7
Miami, Fla.	75.7
Orlando, Fla.	72.4
Pensacola, Fla.	68.0
Tallahassee, Fla.	67.2
Tampa, Fla.	72.0
Vero Beach, Fla.	72.4
West Palm Beach, Fla.	74.6
Athens, Ga.	61.4
Atlanta, Ga.	61.2
Augusta, Ga.	63.2
Columbus, Ga.	64.3
Macon, Ga.	64.7
Savannah, Ga.	65.9
Hilo, Hawaii	73.6
Honolulu, Hawaii	77.0
Kahului, Hawaii	75.5
Lihua, Hawaii	75.2
Boise, Idaho	51.1
Lewiston, Idaho	52.1
Pocatello, Idaho	46.6
Cairo, Ill.	59.1
O'Hare Airport, Chicago, Ill.	49.2
Moline, Ill.	49.5
Peoria, Ill.	50.4
Rockford, Ill.	47.8
Springfield, Ill.	52.6
Evanville, Ind.	55.7
Fort Wayne, Ind.	49.7
Indianapolis, Ind.	52.1
South Bend, Ind.	49.4
Des Moines, Iowa	49.7
Dubuque, Iowa	46.3
Sioux City, Iowa	48.4
Waterloo, Iowa	46.1
Concordia, Kans.	53.2
Dodge City, Kans.	55.1
Goodland, Kans.	50.7
Topeka, Kans.	54.1

(continued)

TABLE A-4. (continued)

Wichita, Kans.	56.4
Cincinnati, Ky.—Airport	53.4
Jackson, Ky.	52.6
Lexington, Ky.	54.9
Louisville, Ky.	56.2
Paducah, Ky.	57.2
Bacon Rouge, La.	67.5
Lake Charles, La.	68.0
New Orleans, La.	68.2
Sheveport, La.	68.4
Caribou, Maine	38.9
Portland, Maine	45.0
Baltimore, Md.	55.1
Blue Hill Observation, Mass.	48.6
Boston, Mass.	51.5
Worcester, Maine	46.8
Alpena, Mich.	42.2
Detroit, Mich.	48.6
Flint, Mich.	46.8
Grand Rapids, Mich.	47.5
Noughton Lake, Mich.	42.9
Lansing, Mich.	47.2
Marquette, Mich.	39.2
Maskegon, Mich.	47.2
Sault St. Marie, Mich.	39.7
Duluth, Minn.	38.2
International Falls, Minn.	36.4
Minnesota-St. Paul, Minn.	44.7
Rochester, Minn.	43.5
Saint Cloud, Minn.	41.4
Jackson, Miss.	64.4
Meridian, Miss.	64.1
Tupelo, Miss.	61.9
Columbia, Mo.	34.1
Kansas City, Missouri Airport	56.3
Kansas City, Mo.	59.1
St. Louis, Mo.	55.4
Springfield, Mo.	55.9
Billings, Mont.	46.7
Glasgow, Mont.	41.6
Great Falls, Mont.	44.7
Havre, Mont.	42.3
Helena, Mont.	43.3
Kalispell, Mont.	42.5
Miles City, Mont.	45.4
Missoula, Mont.	44.1
Grand Island, Nebr.	49.9
Lincoln, Nebr.	50.5
Norfolk, Nebr.	46.3
North Platte, Nebr.	48.1
Omaha, Nebr.—Eppley Airport	51.1
Omaha, Nebr.—City	49.5
Scottsbluff, Nebr.	48.5
Valentine, Nebr.	46.8
Elko, Nev.	46.2
Ely, Nev.	44.4
Las Vegas, Nev.	66.2
Reno, Nev.	49.4
Winnesucca, Nev.	48.8
Concord, N.H.	45.3
Mt. Washington, N.H.	26.6
Atlantic City, N.J.--Airport	53.1
Atlantic City, NJ-City	54.1
Newark, N.J.	54.2
Albuquerque, N. Mex.	56.2
Clayton, N. Mex.	52.9
Roswell, N. Mex.	61.4
Albany, N.Y.	47.2
Binghamton, N.Y.	45.7
Buffalo, N.Y.	47.6
New York Central Park, N.Y.	54.6
New York JFK Airport, N.Y.	53.2
New York—La Guardia Airport, N.Y.	54.3
Rochester, N.Y.	48.0
Syracuse, N.Y.	47.7
Asheville, N.C.	55.5
Cape Hatteras, N.C.	61.9
Charlotte, N.C.	60.0
Greensboro—High Point, N.C.	57.8
Raleigh, N.C.	59.0
Wilmington, N.C.	63.4
Bismarck, N.D.	41.3
Fargo, N.D.	40.5
Williston, N.D.	40.8
Akron, Ohio	49.5
Cleveland, Ohio	49.6
Columbus, Ohio	51.7
Dayton, Ohio	51.9
Mansfield, Ohio	49.5
Toledo, Ohio	48.6
Youngstown, Ohio	48.2
Oklahoma City, Okla.	59.9
Tulsa, Okla.	60.3
Astoria, Oreg.	50.6
Burns, Oreg.	46.6
Eugene, Oreg.	52.5
Medford, Oreg.	53.6
Pendleton, Oreg.	52.5
Portland, Oreg.	53.0
Salem, Oreg.	52.0
Sexton Summit, Oreg.	47.7
Guam, Pac.	78.8
Johnston, Island, Pac.	78.9
Allentown, Pa.	51.0
Erie, Pa.	47.5
Harrisburg, Pa.	53.0
Philadelphia, Pa.	54.3
Pittsburg, Pa.	50.3
Avoca, Pa.	49.1
Williamport, Pa.	58.1

(continued)

TABLE A-4. (continued)

Black Island, R.I.	50.2
Providence, R.I.	50.3
Charleston, S.C., Airport	64.8
Charleston, S.C.-City	64.1
Columbia, S.C.	63.3
Greenville-Spartanburg, S.C.	60.1
Aberdeen, S.D.	43.0
Huron, S.D.	44.7
Rapid City, S.D.	46.7
Sioux Falls, S.D.	45.3
Bristol-Johnson City, Tenn.	55.9
Chattanooga, Tenn.	59.4
Knoxville, Tenn.	58.9
Memphis, Tenn.	61.8
Nashville, Tenn.	59.1
Oak Ridge, Tenn.	57.5
Abilene, Tex.	64.5
Amarillo, Tex.	57.3
Austin, Tex.	68.1
Brownsville, Tex.	73.6
Corpus Christi, Tex.	72.1
Dallas-Fort Worth, Tex.	66.0
Del Rio, Tex.	69.8
El Paso, Tex.	63.4
Galveston, Tex.	69.6
Houston, Tex.	68.3
Lubbock, Tex.	59.9
Midland-Odessa, Tex.	63.5
Port Arthur, Tex.	68.7
San Angelo, Tex.	65.7
San Antonio, Tex.	68.7
Victoria, Tex.	70.1
Waco, Tex.	67.0
Wichita Falls, Tex.	63.3
Milford, Utah	49.1
Salt Lake City, Utah	51.7
Burlington, Vt.	44.1
Lynchburg, Va.	56.0
Norfolk, Va.	59.5
Richmond, Va.	57.7
Roanoke, Va.	56.1
Olympia, Wash.	49.6
Quillayute, Wash.	48.7
Seattle, Wash.--International Airport	51.4
Seattle, Wash.--City	52.7
Spokane, Wash.	47.2
Stampede Pass, Wash.	59.3
Wells Wells, Wash.	54.1
Yakima, Wash.	49.7
Beckley, W. Va.	50.9
Charleston, W. Va.	54.8
Elkins, W. Va.	49.3
Huntington, W. Va.	55.2
Green Bay, Wis.	43.6
La Cross, Wis.	46.1
Madison, Wis.	43.2
Milwaukee, Wis.	46.1
Casper, Wyo.	45.2
Cheyenne, Wyo.	45.7
Lander, Wyo.	44.4
Sheridan, Wyo.	44.6

Source: Reference 17.

TABLE A-5. RIM SEAL LOSS FACTORS (K_S for Floating Roof Tanks)[a]

Tank construction and rim seal system	Average fitting seals		Tight fitting seals[b]	
	K_S (lb-mole / [mi/h]^n ft yr)	n (dimensionless)	K_S (lb-mole / [mi/h]^n ft yr)	n (dimensionless)
Welded External Floating Roof Tanks[c]				
1. Mechanical shoe seal				
a. Primary only	1.2[c]	1.5[c]	0.8	1.6
b. Shoe-mounted secondary	0.8	1.2	0.8	1.1
c. Rim-mounted secondary	0.2	1.0	0.2	0.9
2. Liquid-mounted resilient filled seal				
a. Primary only	1.1	1.0	0.5	1.1
b. Weather shield	0.8	0.9	0.5	1.0
c. Rim-mounted secondary	0.7	0.4	0.5	0.5
3. Vapor-mounted resilient filled seal				
a. Primary only	1.2	2.3	1.0	1.7
b. Weather shield	0.9	2.2	1.1	1.6
c. Rim-mounted secondary	0.2	2.6	0.4	1.5
Riveted External Floating Roof Tanks[c]				
1. Mechnical shoe seal				
a. Primary only	1.3	1.5	d	
b. Shoe-mounted secondary	1.4	1.2	d	
c. Rim-mounted secondary	0.2	1.6	d	
Welded Internal Floating Roof Tanks[e]				
Liquid mounted resilient seal				
Primary seal only	3.0	0	NA[f]	NA[f]
With rim mounted secondary seal[g]	1.6	0	NA[f]	NA[f]
Vapor mounted resilient seal				
Primary seal only	6.7	0	NA[f]	NA[f]
With rim mounted secondary seal[g]	2.5	0	NA	NA

[a] The rim seal loss factors (K_S, n) may be used for wind speeds from 2 to 15 mi/h.
[b] No evaporative loss information is available for riveted tanks with consistently tight fitting rim seal system.
[c] If no specific information is available, a welded tank with an average fitting mechanical shoe primary seal only can be assumed to represent the most common or typical tank construction and rim seal system in use.
[d] Seal tightness criteria are defined in Section 1.2.1.1.
[e] Based on emissions from tank seal systems in reasonably good working condition, nonvisible holes, tears, or usually large gaps between the seals and the tank wall. The applicability of K_S decreases in cases where the actual gaps exceed the gaps assumed during development of the correlation.
[f] NA = Not applicable or not available.
[g] If tank specific information is not available about the secondary seal on an internal floating roof tank, then assume only a primary seal is present.

TABLE A-6. AVERAGE ANNUAL WIND SPEED (v, mi/h) FOR SELECTED U.S. LOCATIONS

Birmingham, Ala.	7.3
Huntsville, Ala.	8.1
Mobile, Ala.	9.0
Montgomery, Ala.	6.7
Anchorage, Alaska	6.8
Annette, Alaska	10.6
Barrow, Alaska	11.8
Barter Alaska	13.2
Bethel, Alaska	12.8
Bettles, Alaska	6.7
Big Delta, Alaska	8.2
Gold Bay, Alaska	16.9
Fairbanks, Alaska	5.4
Gulkana, Alaska	6.8
Homer, Alaska	7.2
Juneau, Alaska	8.4
King Salmon, Alaska	10.7
Kodiak, Alaska	10.6
Kotzebue, Alaska	13.0
McGrath, Alaska	5.1
Nome, Alaska	10.7
St. Paul Island, Alaska	18.3
Talkeetna, Alaska	4.5
Valdez, Alaska	6.0
Yakutat, Alaska	7.4
Flagstaff, Ariz.	7.3
Phoenix, Ariz.	6.3
Tucson, Ariz.	8.2
Winslow, Ariz.	8.9
Yuma, Ariz.	7.8
Fort Smith, Ark.	7.6
Little Rock, Ark.	8.0
Bakersfield, Calif.	6.4
Blue Canyon, Calif.	7.7
Eureka, Calif.	6.8
Fresno, Calif.	6.4
Long Beach, Calif.	6.4
Los Angeles, Calif.—International Airport	7.5
Los Angeles, Calif.	6.2
Mount Shasta, Calif.	5.1
Oakland, Calif.	8.2
Red Bluff, Calif.	8.6
Sacramento, Calif.	8.1
San Diego, Calif.	6.8
San Francisco, Calif.—International Airport	10.5
San Francisco, Calif.—City	8.7
Santa Maria, Calif.	7.0
Stockton, Calif.	7.5
Colorado Springs, Colo.	10.1
Denver, Colo.	8.8
Grand Junction, Colo.	8.1
Pueblo, Colo.	8.7
Bridgeport, Conn.	12.0
Hartford, Conn.	8.5
Wilmington, Del.	9.2
Wash., D.C.-Dulles Airport	7.5
Wash. D.C.-National Airport	9.3
Apalachicola, Fla.	7.9
Daytona Beach, Fla.	8.8
Fort Myers, Fla.	8.2
Jacksonville, Fla.	8.2
Key West, Fla.	11.2
Miami, Fla.	9.2
Orlando, Fla.	8.6
Pensacola, Fla.	8.4
Tallahassee, Fla.	6.5
Tampa, Fla.	8.6
West Palm Beach, Fla.	9.5
Athens, Ga.	7.4
Atlanta, Ga.	9.1
Auqueta, Ga.	6.5
Columbus, Ga.	6.7
Macon, Ga.	7.7
Savannah, Ga.	7.9
Hilo, Hawaii	7.1
Honolulu, Hawaii	11.6
Kahului, Hawaii	12.8
Lihua, Hawaii	11.9
Boise, Idaho	8.9
Pocatello, Idaho	10.2
Cairo, Ill.	8.5
Chicago, Ill.	10.3
Moline, Ill.	10.0
Peoria, Ill.	10.1
Rockford, Ill.	9.9
Springfield, Ill.	11.3
Evansville, Ind.	8.2
Fort Wayne, Ind.	10.2
Indianapolis, Ind.	9.6
South Bend, Ind.	10.4
Des Moines, Iowa	10.9
Sioux City, Iowa	11.0
Waterloo, Iowa	10.7
Concordia, Kans.	12.3
Dodge City, Kans.	13.9
Goodland, Kans.	12.6
Topeka, Kans.	10.2
Wichita, Kans.	12.4
Cincinnati, Ky.—Airport	9.1
Jackson, Ky.	7.0
Lexington, Ky.	9.5
Louisville, Ky.	8.3
Baton Rouge, La.	7.7
Lake Charles, La.	8.7
New Orleans, La.	8.2

(continued)

TABLE A-6. (continued)

Sheveport, La.	8.6
Caribou, Maine	11.2
Portland, Maine	8.7
Baltimore, Md.	9.2
Blue Hill Observation, Mass.	15.4
Boston, Mass.	12.4
Worcester, Mass.	10.2
Alpena, Mich.	7.9
Detroit, Mich.	10.2
Flint, Mich.	10.3
Grand Rapids, Mich.	9.8
Noughton Lake, Mich.	8.9
Lansing, Mich.	10.1
Maskegon, Mich.	10.7
Sault Ste. Marie, Mich.	9.4
Duluth, Minn.	11.2
International Falls, Minn.	9.0
Minnesota-St. Paul, Minn.	10.5
Rochester, Minn.	12.9
Saint Cloud, Minn.	8.0
Jackson, Miss.	7.4
Meridian, Miss.	6.0
Columbia, Mo.	9.8
Kansas City, Missouri Airport	10.7
Kansas City, Mo.	9.9
St. Louis, Mo.	9.7
Springfield, Mo.	10.9
Billings, Mont.	11.3
Glasgow, Mont.	10.8
Great Falls, Mont.	12.8
Havre, Mont.	9.9
Helena, Mont.	7.8
Kalispell, Mont.	6.6
Miles City, Mont.	10.2
Missoula, Mont.	6.1
Grand Island, Nebr.	12.0
Lincoln, Nebr.	10.4
Norfolk, Nebr.	11.8
North Platte, Nebr.	10.3
Omaha, Nebr.	10.6
Scottsbluff, Nebr.	10.6
Valentine, Nebr.	10.0
Elke, Nev.	6.0
Ely, Nev.	10.4
Las Vegas, Nev.	9.2
Reno, Nev.	6.5
Winnemucca, Nev.	7.9
Concord, N.H.	6.7
Mt. Washington, N.H.	35.1
Atlantic City, N.J.	10.2
Newark, N.J.	10.2
Albuquerque, N. Mex.	9.1
Roswell, N. Mex.	8.7
Albany, N.Y.	8.9
Binghamton, N.Y.	10.3
Buffalo, N.Y.	12.1
New York Central Park, N.Y.	9.4
New York--La Guardia Airport, N.Y.	12.3
Rochester, N.Y.	9.8
Syracuse, N.Y.	9.7
Asheville, N.C.	7.6
Cape Hatteras, N.C.	11.4
Charlotte, N.C.	7.5
Greensboro--High Point, N.C.	7.6
Raleigh, N.C.	7.8
Wilmington, N.C.	8.9
Bismarck, N.D.	10.3
Fargo, N.D.	12.5
Williston, N.D.	10.1
Akron, Ohio	9.8
Cleveland, Ohio	10.7
Columbus, Ohio	8.7
Dayton, Ohio	10.1
Mansfield, Ohio	11.0
Toledo, Ohio	9.4
Youngstown, Ohio	10.0
Oklahoma City, Okla.	12.5
Tulsa, Okla.	10.4
Astoria, Oreg.	8.5
Eugene, Oreg.	7.6
Medford, Oreg.	4.8
Pendleton, Oreg.	9.0
Portland, Oreg.	7.9
Salem, Oreg.	7.0
Sexton Summit, Oreg.	11.8
Allentown, Pa.	9.2
Erie, Pa.	11.2
Harrisburg, Pa.	7.7
Philadelphia, Pa.	9.5
Pittsburg, Pa.--International Airport	9.2
Avoca, Pa.	8.4
Williamport, Pa.	7.9
San Juan, P.R.	8.5
Providence, R.I.	10.6
Charleston, S.C.	8.7
Columbia, S.C.	6.9
Greenville-Spartanburg, S.C.	6.7
Aberdeen, S.D.	11.2
Huron, S.D.	11.7
Rapid City, S.D.	11.2
Sioux Falls, S.D.	11.1
Bristol-Johnson City, Tenn.	5.6
Chattanooga, Tenn.	6.2
Knoxville, Tenn.	7.1
Memphis, Tenn.	9.0
Nashville, Tenn.	8.0
Oak Ridge, Tenn.	4.4
Abilene, Tex.	12.2
Amarillo, Tex.	13.7

(continued)

TABLE A-6. (continued)

Austin, Tex.	9.3
Brownsville, Tex.	11.6
Corpus Christi, Tex.	12.0
Dallas-Fort Worth, Tex.	10.8
Del Rio, Tx.	9.9
El Paso, Tex.	9.2
Galveston, Tex.	11.0
Houston, Tex.	7.8
Lubbock, Tex.	12.4
Midland-Odessa, Tex.	11.1
Port Arthur, Tex.	9.9
San Angelo, Tex.	10.4
San Antonio, Tex.	9.4
Victoria, Tex.	10.0
Waco, Tex.	11.3
Wichita Falls, Tex.	11.7
Salt Lake City, Utah	8.8
Burlington, Vt.	8.8
Lynchburg, Va.	7.8
Norfolk, Va.	10.5
Richmond, Va.	7.5
Roanoke, Va.	8.3
Olympia, Wash.	6.7
Quillayuta, Wash.	6.1
Seattle, Wash.--International Airport	9.1
Spokane, Wash.	8.7
Walla Walla, Wash.	5.3
Yakima, Wash.	7.1
Beckley, W. Va.	9.3
Charleston, W. Va.	6.4
Elkins, W. Va.	6.2
Huntington, W. Va.	6.5
Green Bay, Wis.	10.1
La Crosse, Wis.	8.8
Madison, Wis.	9.8
Milwaukee, Wis.	11.6
Casper, Wyo.	12.9
Cheyenne, Wyo.	12.9
Lander, Wyo.	6.9
Sheridan, Wyo.	8.1

Source: Reference 17.

TABLE A-7. AVERAGE CLINGAGE FACTORS (C_F)
(bbl/1,000 ft^2)

Liquid	Shell condition		
	Light rust[a]	Dense rust	Gunite lined
Gasoline	0.0015	0.0075	0.15
Single component stocks	0.0015	0.0075	0.15
Crude oil	0.0060	0.030	0.60

[a]If no specific information is available, these values can be assumed to represent the most common condition of tanks currently in use.

TABLE A-8. EXTERNAL ROOF FITTING LOSS FACTORS (K_{fa}, K_{fb}) AND TYPICAL NUMBER OF ROOF FITTINGS (N_F)[a]

Roof fitting type and construction details	Roof fitting loss factors: K_{fa} $\left(\frac{\text{lb-mole}}{\text{yr}}\right)$	Roof fitting loss factors: K_{fb} $\left(\frac{\text{lb-mole}}{(\text{mi/h})^n\ \text{yr}}\right)$	Roof fitting loss factors: m (dimensionless)	Typical No. of fittings, N_F[b]
1. Access hatch (24-inch diameter well)				1
a. Bolted cover, gasketed	0	0	0[b]	
b. Unbolted cover, ungasketed	2.7	7.1	1.0	
c. Unbolted cover, gasketed	2.9	0.41	1.0	
2. Guide pole well (8-inch diameter unslotted pole, 21-inch diameter well)				1
a. Ungasketed sliding cover	0	67	0.98[b]	
b. Gasketed sliding cover	0	3.0	1.4	
3. Guide pole/sample well (8-inch diameter slotted pole, 21-inch diameter well)				c
a. Ungasketed sliding cover, without float	0	310	1.2	
b. Ungasketed sliding cover, with float	0	29	2.0	
c. Gasketed sliding cover, without float	0	260	1.2	
d. Gasketed sliding cover, with float	0	8.5	2.4	
4. Gauge float well (20-inch diameter well)				1
a. Unbolted cover, ungasketed	2.3	5.9	1.0[b]	
b. Unbolted cover, gasketed	2.4	0.34	1.0	
c. Bolted cover, gasketed	0	0	0	
5. Gauge hatch/sample well (8-inch diameter well)				1
a. Weighted mechanical actuation, gasketed	0.95	0.14	1.0[b]	
b. Weighted mechanical actuation, ungasketed	0.91	2.4	1.0	
6. Vacuum breaker (10-inch diameter well)				See Table A-9
a. Weighted mechanical actuation, gasketed	1.2	0.17	1.0[b]	
b. Weighted mechanical actuation, ungasketed	1.1	3.0	1.0	
7. Roof drain (3-inch diameter)				See Table A-9
a. Open	0	7.0	1.4[e]	
b. Closed, 90 percent	0.51	0.81	1.0[e]	

(continued)

TABLE A-8. (continued)

Roof fitting type and construction details	Roof fitting loss factors: K_{fa} $\left(\frac{\text{lb-mole}}{\text{yr}}\right)$	K_{fb} $\left(\frac{\text{lb-mole}}{[\text{mi/h}]^n\ \text{yr}}\right)$	m (dimensionless)	Typical No. of fittings, N_F[b]
8. Roof leg (3-inch diameter leg)				See Table A-10
a. Adjustable, pontoon area	1.5	0.20	1.0[b]	
b. Adjustable, center area	0.25	0.067	1.0[b]	
c. Adjustable, double-deck roofs	0.25	0.067	1.0	
d. Fixed	0	0	0	
Roof leg (2½ inch diameter leg)				
e. Adjustable, pontoon area	1.7	0	0	
f. Adjustable, center area	0.41	0	0	
g. Adjustable, double-deck roofs	0.41	0	0	
h. Fixed	0	0	0	
9. Rim vent (6-inch diameter)				1.0[d]
a. Weighted mechanical actuation, gasketed	0.71	0.10	1.0[b]	
b. Weighted mechanical actuation, ungasketed	0.68	1.8	1.0	

[a]The roof fitting loss factors (K_{fa}, K_{fb}, m) may be used only for wind speeeds from 2 to 15 mi/h.

[b]If no specific information is available, this value can be assumed to represent the most common or typical roof fittings currently in use.

[c]Guide pole/sample well is an optional fitting not typically used.

[d]Rim vents are used only with mechanical shoe primary seals.

[e]Roof drains that drain excess rainwater into the product are not used on pontoon floating roofs. They are, however, used on double-deck floating roofs and are typically left "open."

TABLE A-11. SUMMARY OF INTERNAL FLOATING DECK FITTING LOSS FACTORS (K_F) AND TYPICAL NUMBER OF FITTINGS (N_F)[a]

Deck fitting type	Deck fitting loss factor, K_F (lb-mol/yr)	Typical No. of fittings, N_F
Access hatch		1
Bolted cover, gasketed	1.6	
Unbolted cover, gasketed	11	
Unbolted cover, ungasketed	25[b]	
Automatic gauge float well		1
Bolted cover, gasketed	5.1	
Unbolted cover, gasketed	15	
Unbolted cover, ungasketed	28[b]	
Column well		(see Table A-12)
Builtup column-sliding cover, gasketed	33	
Builtup column-sliding cover, ungasketed	47[b]	
Pipe column-flexible fabric sleeve seal	10	
Pipe column-sliding cover, gasketed	19	
Pipe column-sliding cover, ungasketed	32	
Ladder well		1
Sliding cover, gasketed	56	
Sliding cover, ungasketed	76[b]	
Roof leg or hanger well		$(5+\frac{D}{10}+\frac{D^2}{600})$[d]
Adjustable	7.9[b]	
Fixed	0	
Sample pipe or well		1
Slotted pipe-sliding cover, gasketed	44	
Slotted pipe-sliding cover, ungasketed	57	
Sample well-slit fabric seal, 10 percent open area	12[b]	
Stub drain, 1 inch diameter[c]	1.2	$(\frac{D^2}{125})$[d]
Vacuum breaker		1
Weighted mechanical actuation, gasketed	0.7[b]	
Weighted mechanical actuation, ungasketed	0.9	

[a]For windpseeds ranging from 2 to 15 miles/h.
[b]If no specific information is available, this value can be assumed to represent the most common/typical deck fittings currently used.
[c]Not used in welded contact internal floating decks.
[d]D = tank diameter, ft.

TABLE A-12. TYPICAL NUMBER OF COLUMNS (N_C) AS A FUNCTION OF TANK DIAMETER (D) FOR INTERNAL FLOATING ROOF TANKS WITH COLUMN SUPPORTED FIXED ROOFS[a]

Tank diameter range of D (ft)	Typical number columns, N_C
$0 < D \leq 85$	1
$85 < D \leq 100$	6
$100 < D \leq 120$	7
$120 < D \leq 135$	8
$135 < D \leq 150$	9
$150 < D \leq 170$	16
$170 < D \leq 190$	19
$190 < D \leq 220$	22
$220 < D \leq 235$	31
$235 < D \leq 270$	37
$270 < D \leq 275$	43
$275 < D \leq 290$	49
$290 < D \leq 330$	61
$330 < D \leq 360$	71
$360 < D \leq 400$	81

[a]This table was derived from a survey of users and manufacturers. The actual number of columns in a particular tank may vary greatly with age, fixed roof style, loading specifications, and manufacturing prerogatives. Data in this table should not supercede information on actual tanks.

TABLE A-9. TYPICAL NUMBER OF EXTERNAL FLOATING ROOF VACUUM BREAKERS AND DRAINS[a]

Tank diameter, d (ft)[b]	Vacuum breakers, Pontoon roof	Vacuum breakers, Double-deck roof	Roof drains Double-deck roof[c]
50	1	1	1
100	1	1	1
150	2	2	2
200	3	2	3
250	4	3	5
300	5	3	7
350	6	4	--
400	7	4	--

[a]This table was derived from a survey of users and manufacturers. The actual number of vacuum breakers may vary greatly depending on throughput and manufacturing prerogatives. The actual number of roof drains may also vary greatly depending on the design rainfall and manufacturing prerogatives. For tanks over 300 ft diameter, actual tank data or manufacturer's recommendations may be needed for the number of roof drains. This table should not supersede information based on actual tank data.

[b]If the actual diameter is between the diameters listed in this table, use the closest diameter listed. If midway, use the next larger diameter.

[c]Roof drains that drain excess rainwater into the product are not used on pontoon floating roofs. They are, however, used on double-deck floating roofs and are typically left "open."

TABLE A-10. TYPICAL NUMBER OF EXTERNAL FLOATING ROOF LEGS[a]

Tank diameter, d (ft)[b]	Vacuum breakers		Double-deck roof
	Pontoon roof	Center legs	
30	4	2	6
40	4	4	7
50	6	6	8
60	9	7	10
70	13	9	13
80	15	10	16
90	16	12	20
100	17	16	25
110	18	20	29
120	19	24	34
130	20	28	40
140	21	33	46
150	23	38	52
160	26	42	58
170	27	49	66
180	28	56	74
190	29	62	82
200	30	69	90
210	31	77	98
220	32	83	107
230	33	92	115
240	34	101	127
250	35	109	138
260	36	118	149
270	36	128	162
280	37	138	173
290	38	148	186
300	38	156	200
310	39	168	213
320	39	179	226
330	40	190	240
340	41	202	255
350	42	213	270
360	44	226	285
370	45	238	300
380	46	252	315
390	47	266	330
400	48	281	345

[a]This table was derived from a survey of users and manufacturers. The actual number of roof legs may vary greatly depending on age, floating roof style, loading specifications, and manufacturing prerogatives. This table should not supersede information based on actual tank data.

[b]If the actual diameter is between the diameters listed in this table, use the closest diameter listed. If midway, use the next larger diameter.

TABLE A-13. DECK SEAM LENGTH FACTORS (S_D) FOR TYPICAL DECK CONSTRUCTIONS FOR INTERNAL FLOATING ROOF TANKS[a]

Deck construction	Typical deck seam length factor S_D (ft/ft^2)
Continuous sheet construction[b]	
5 ft wide sheets	0.20[c]
6 ft wide sheets	0.17
7 ft wide sheets	0.14
Panel construction[d]	
5x7.5 ft rectangular	0.33
5x12 ft rectangular	0.28

[a]Deck seam loss applies to bolted decks only.
[b]S_D = 1/W, where W = sheet width (ft).
[c]If no specific information is available, these factors can be assumed to represent the most common bolted decks currently in use.
[d]S_D = (L+W)/LW, where W = panel width (ft) and L = panel length (ft).

APPENDIX B.

GLOSSARY OF SYMBOLS AND EXAMPLES

TABLE B-1. GLOSSARY OF SYMBOLS

Symbol	Name	Units	Description
A_{deck}	Area of deck	ft^2	
C	Small diameter tank adjustment factor	—	—
C_F	Shell clingage factor	$bbl/10^3\ ft^2$	—
D	Diameter of tank	ft	—
F_C	Effective column diameter	ft	Column perimeter/π
F_P	Paint factor	—	Correction factor for color of storage tank
F_F	Total deck fitting loss factor	lb-mol/yr	—
H	Vapor space height	ft	Average vapor space height, including roof volume correction
K_C	Product factor	—	—
K_D	Deck seam loss per unit seam length factor	lb-mol/ft yr	
K_{fa_i}	roof fitting loss factor	lb-mol/yr	—
K_{fb_i}	roof fitting loss factor	lb-mol/yr	—
K_{F_i}	Roof/deck fitting loss factor for a particular type of fitting (i)	lb-mol/yr	—
K_N	Turnover factor	—	—
K_S	Seal factor	$lb\text{-}mol/(ft(mi/h)^n)$	—
L_B	Breathing loss from a tank	lb/yr	—
L_D	Deck seam loss	lb/yr	From an internal or external floating roof tank
L_F	Deck fitting loss	lb/yr	From an internal floating roof tank
L_R	Rim seal loss	lb/yr	From floating roof tanks
L_{RF}	Roof fitting loss	lb/yr	From external floating roof tank
L_{seam}	Length of deck	ft	
L_T	Total estimated loss from a tank	lb/yr	—
L_W	Working loss from a tank	lb/yr	—
L_{WD}	Withdrawal loss	lb/yr	From floating roof tanks
m	Exponent for roof fitting loss factor	—	—

(continued)

TABLE B-1. (continued)

Symbol	Name	Units	Description
M_V, M_i	Molecular weight	lb/lb-mol	Molecular weight of vapor (or component i) in tank
n	Seal-related windspeed exponent	--	--
n_f	Total number of different types of fittings	--	
N	Number of turnovers per year	--	Throughput/volume
N_C	Number of columns	--	Number of columns in column-supported tank
N_{F_i}	Number of deck fittings of a particular type	--	--
P^*	Vapor pressure function	--	--
P_i, P	True vapor pressure	psia	True vapor pressure of component at bulk liquid conditions
$P^o_{i,t}$	Vapor pressure of pure component i at temperature t	psia	
$P_{partial}$	Partial pressure	psia	
P_A	Atmospheric pressure	psia	Average atmospheric pressure at tank location
P_T	Total vapor pressure of a mixture	psia	--
Q	Annual tank throughput	bbl/yr	Tank capacity X number of turnovers
RVP	Reid vapor pressure	psia	
S_D	Deck seam length factor	ft/ft^2	Length/area of deck
T_S	Storage temperature	°F	
v	Average windspeed at tank site	mi/h	--
V	Tank volume	gal	--
W_L	Average liquid density	lb/gal	--
ΔT	Average ambient diurnal temperature change	°F	--
x_i	Mole fraction of component in liquid	--	--
y_i	Mole fraction of component in vapor	--	--

B.1 CHEMICAL MIXTURE IN A FIXED ROOF TANK

Determine the yearly emission rate of product and of each component from a vertical, fixed roof storage tank containing (for every 3,171 pounds [lb] of liquid mixture) 2,812 lb of benzene, 258 lb of toluene, and 101 lb of cyclohexane. The tank is not heated and the average yearly ambient temperature of the area is 67°F. The tank is 6 feet (ft) in diameter and 10 ft high and is painted white. The tank volume is 2,100 gallons. The number of turnovers per year for the tank is five (i.e., the throughput of the tank is 10,500 gal/yr).

Solution:

1. Determine tank type

The tank is a vertical, fixed roof storage tank.

2. Determine estimating methodology

The product is made up of three organic liquids, all of which are miscible in each other, which make a homogenous mixture if the material is well mixed. The tank emission rate will be based upon the properties of the mixture. Since the components have similar structures and molecular weights, Raoult's Law is assumed to apply to the mixture.

3. Select equations to be used

For a vertical, fixed roof storage tank, the following equations apply:

$$L_T = L_B + L_W$$

$$L_B = 2.26X10^{-2} M_V \left(\frac{P}{P_A - P}\right)^{0.68} D^{1.73} H^{0.51} \Delta T^{0.5} F_p C K_C$$

$$L_W = 2.40x10^{-5} M_V P V N K_N K_C$$

where:

L_T = total loss, lb/yr of VOC

L_B = breathing loss, lb/yr of VOC

L_W = working loss, lb/yr of VOC

M_V = molecular weight of product vapor, lb/lb-mol

P = true vapor pressure of product, psia

P_A = atmospheric pressure, psia

D = tank diameter, ft

H = average vapor space height, ft: use tank-specific values or an assumed value of one-half the tank height

ΔT = average diurnal temperature change in °F

F_P = paint factor (dimensionless); see Table A-1

C = tank diameter factor (dimensionless):

for diameter $\geq$30 feet, C = 1

for diameter <30 feet,

$C = 0.0771\ (D) - 0.0013(D^2) - 0.1334$

K_C = product factor (dimensionless) = 1.0 for volatile organic liquids, 0.65 for crude oil

V = tank capacity, gal

N = number of turnovers per year (dimensionless)

$$= \frac{\text{throughput, gal/yr}}{\text{tank capacity, gal}}$$

K_N = turnover factor (dimensionless):

for turnovers >36, $K_N = \frac{180+N}{6N}$

for turnovers $\leq$36, $K_N = 1$

4. <u>Identify parameters to be calculated or determined from tables</u>

In this example, the following parameters are <u>not</u> specified: M_V, P, ΔT, H, P_A, and F_P. Some typical assumptions that can be made are:

$H = \frac{1}{2}$ tank height $= \frac{1}{2}(10) = 5$ ft

F_P = 1.0 for clean white paint (Table A-1)

ΔT = 20°F

P_A = atmospheric pressure = 14.7 psia

K_C = 1.0 for volatile organic liquids

The tank diameter factor can be found in Figure A-1 or calculated as follows:

$$C = 0.0771(6) - 0.0013(6)^2 - 0.1334$$

$$C = 0.282$$

The vapor pressure (P) of the liquid and the molecular weight of the vapor (M_V) still need to be calculated.

5. Calculate mole fractions in the liquid

The mole fractions of components in the liquid must be calculated in order to calculate the vapor pressure of the liquid using Raoult's Law.

The molecular weight for each component (M_i) can be read from Table A-2.

Component	Amount, lb	÷	M_i	=	Moles	x_i
Benzene	2,812		78.1		36.0	0.90
Toluene	258		92.1		2.80	0.07
Cyclohexane	101		84.2		1.20	0.03
Total					40.0	1.00

M_i = molecular weight, lb/lb-mol
x_i = $moles_i$/total moles = 36.0/40.0 = 0.900 for benzene

6. Calculate partial pressures and total vapor pressure of the liquid

The vapor pressure of the mixture may be found by first obtaining the vapor pressures of each component at the average yearly temperature from Table A-2. For temperatures not listed in the table, interpolation between values is required.

Material	Vapor pressure, psia 60°F	70°F
Benzene	1.2	1.5
Toluene	0.3	0.4
Cyclohexane	1.2	1.6

Because the average temperature falls between two temperature values on the table (60°F and 70°F), interpolation between temperatures is necessary. The vapor pressure for each component at 67°F may be calculated through interpolation in the following manner:

Benzene

T_{actual} = 67°F

T_1 = 60°F

T_2 = 70°F

P_1 = 1.2

P_2 = 1.5

$(T-T_{actual})_1$ = -7

$(T-T_{actual})_2$ = 3

	T °F	P, psia	$(T-T_{actual})$, °F
1	60	1.2	(-7)
2	70	1.5	(3)

$$P_{\text{benzene at } 67°F} = \frac{1}{T_2-T_1}[(T-T_{actual})_2(P_1)-(T-T_{actual})_1(P_2)]$$

$$P_{\text{benzene at } 67°F} = \frac{1}{(70-60)}[(3)(1.2)-(-7)(1.5)]$$

$$P_{\text{benzene at } 67°F} = \frac{1}{10}[14.1]$$

$$P_{\text{benzene at } 67°F} = 1.4 \text{ psia}$$

Similarly, vapor pressures for the two remaining components are calculated as:

Toluene: P(at 67°F) = 0.37 psia

Cyclohexane: P(at 67°F) = 1.5 psia

Using these vapor pressures of the pure components and the liquid mole fractions calculated in Step 5, the partial pressures of the three components can be calculated.

According to Raoult's Law, the partial pressure of a component is the product of its pure vapor pressure and its liquid mole fraction.

Component	P at 67°F	X	x_i	=	$P_{partial}$
Benzene	1.4		0.90		1.26
Toluene	0.37		0.07		0.0259
Cyclohexane	1.5		0.03		0.045
			1.00		1.33

The vapor pressure of the mixture is 1.33 psia.

7. Calculate mole fractions in the vapor

The mole fractions of the vapor phase are based upon the partial pressure that each component exerts (calculated in Step 6).

The total vapor pressure of the mixture is 1.33 psia; so, for benzene,

$$y_{benzene} = \frac{P_{partial}}{P_{total}} = \frac{1.26}{1.33} = 0.947$$

where

$y_{benzene}$ = mole fraction of benzene in the vapor

$P_{partial}$ = partial pressure of benzene

P_{total} = total vapor pressure of the mixture

Similarly for toluene and cyclohexane,

$$y_{toluene} = \frac{0.0259}{1.33} = 0.0195$$

$$y_{cyclohexane} = \frac{0.045}{1.33} = 0.0338$$

The vapor phase mole fractions sum to 1.0.

8. Calculate molecular weight of the vapor

The molecular weight of the vapor is dependent upon the mole fractions of the components in the vapor.

$$M_V = \Sigma M_i y_i$$

where

M_V = molecular weight of the vapor

M_i = molecular weight of the component

y_i = mole fraction of the component in the vapor

Component	M_i	X	y_i	=	$(M_i)(y_i)$
Benzene	78.1		0.947		73.961
Toluene	92.1		0.0195		1.7959
Cyclohexane	84.2		0.0338		2.8459
			1.00		78.6

The molecular weight of the vapor is 78.6 lb/lb-mol.

9. Calculate weight fractions of the vapor

The weight fractions of the vapor are needed to calculate the amount (in pounds) of each component emitted from the tank. The weight fractions are related to the previously calculated mole fractions. First, assume that there are 1,000 moles of vapor present. Using this assumption, the weight fractions calculated will be valid no matter how many moles actually are present. The number of moles for each component will be 1,000 times the mole fraction of the component (y_i).

Component	No. of moles	X	M_i	=	$Pounds_i$	Weight fraction
Benzene	947		78.1		73,961	0.941
Toluene	19.5		92.1		1,796	0.0228
Cyclohexane	33.8		84.2		2,846	0.0362
	1,000				78,603	1.00

The weight fraction of each component is the pounds of that component divided by the total pounds of the mixture. For example,

$$\text{weight fraction}_{\text{benzene}} = \frac{73,961}{78,603} = 0.941.$$

Simarly, toluene = 0.0228 and cyclohexane = 0.0362.

10. <u>Calculate total VOC emitted from the tank</u>

The total VOC emitted from the tank is calculated using the equations identified in Step 3 and the parameters calculated in Steps 4 through 9.

$$L_T = L_B + L_W$$

where:

L_T = total loss, lb/yr of VOC

L_B = total breathing loss, lb/yr of VOC

L_W = total working loss, lb/yr of VOC

$$L_B = 2.26\times10^{-2} M_V \left(\frac{P}{P_A - P}\right)^{0.68} D^{1.73} H^{0.51} \Delta T^{0.5} F_p C K_C$$

where:

M_V = 78.6 lb/lb-mol (from Step 8)

P = 1.3 psia (from Step 6)

P_A = 14.7 psia (from Step 4)

D = 6 ft (given)

H = 5 ft (from Step 4)

ΔT = 20°F (from Step 4)

F_p = 1.0 (from Step 4)

C = 0.282 (from Step 4)

K_C = 1 (from Step 4)

$$L_B = 2.26\times10^{-2}(78.6)\left(\frac{1.3}{14.7-1.3}\right)^{0.68}(6)^{1.73}(5)^{0.51}(20)^{0.5}(1)(0.282)(1)$$

L_B = 23.1 lb/yr of VOC

$L_W = 2.40 \times 10^{-5}\ M_V P V N K_N K_C$

where

M_V = 78.6 lb/lb-mol (from Step 4)
P = 1.3 psia (from Step 6)
V = 2,100 gal (given)
N = 5 (given)
K_N = 1 (from Step 3)
K_C = 1 (from Step 4)

$L_W = 2.40 \times 10^{-5}(78.6)(1.3)(2{,}100)(5)(1)(1)$

L_W = 25.7 lb/yr of VOC

L_T = 23.1+25.7

L_T = 48.8 lb/yr of VOC emitted from the tank

11. <u>Calculate amount of each component emitted from the tank</u>

The amount of each component emitted is the weight fraction of that component in the vapor (calculated in Step 9) times the amount of total VOC emitted.

Component	Weight fraction	x48.8 lb =	Pounds emitted/yr
Benzene	0.941		45.9
Toluene	0.0228		1.11
Cyclohexane	0.0362		1.77
	1.00		48.8

For benzene,

$$\frac{0.941 \text{ lb of benzene}}{1 \text{ lb of VOC}} \times 48.8 \text{ lb of VOC} = 45.9 \text{ lb of benzene emitted}$$

To calculate the liquid volume that is emitted for each component, the density of the compound is used. The density for these three components can be taken from Table A-2.

Component	Density, lb/gal	Amount emitted, lb/yr	Volume emitted, gal/yr
Benzene	7.4	45.9	6.2
Toluene	7.3	1.11	0.15
Cyclohexane	6.5	1.77	0.27

where

$$\text{volume, gal/yr} = \frac{\text{amount, lb/yr}}{\text{density, lb/gal}}$$

B.2 CHEMICAL MIXTURE IN AN EXTERNAL FLOATING ROOF TANK

Determine the yearly emission rate of a mixture that is 75 percent benzene, 15 percent toluene, and 10 percent cyclohexane, by weight, from a 100,000 gallon external floating roof tank with a pontoon roof. The tank is 20 feet in diameter. The average yearly temperature in the area is 70°F and the average wind speed is 10 mph. The tank has 10 turnovers per year. The tank roof has no support columns. The tank has a mechanical shoe seal (primary seal) and a shoe-mounted secondary seal. The tank is made of welded steel and has a light rust covering on the inside surface of the shell. The floating roof is equipped with the following fittings: (1) an ungasketed access hatch with an unbolted cover, (2) an unspecified number of ungasketed vacuum breakers with weighted mechanical actuation, and (3) ungasketed gauge hatch/sample wells with weighted mechanical actuation.

Solution:

1. Determine tank type

The tank is an external floating roof storage tank.

2. Determine estimating methodology

The product consists of three organic liquids, all of which are miscible in each other, which make a homogenous mixture if the material is well mixed. The tank emission rate will be based upon the properties of the mixture. Since the components have similar structures and molecular weights, Raoult's Law is assumed to apply to the mixture.

3. Select equations to be used

For an external floating roof tank,

$$L_T = L_{WD}+L_R+L_{RF}$$

$$L_{WD} = (0.943)\ QC_FW_L/D\ [1+\frac{N_CF_C}{D}]$$

$$L_{RF} = F_FP^*M_VK_C$$

$$L_R = K_Sv^nP^*DM_VK_C$$

where:

L_T = total loss, lb/yr of VOC

L_{WD} = withdrawal loss, lb/yr of VOC

L_R = rim seal loss from external floating roof tanks, lb/yr of VOC

L_{RF} = roof fitting loss, lb/yr of VOC

Q = product average throughput (bbl/yr)

C_F = product withdrawal shell clingage factor (bbl/10^3 ft^2); see Table A-7

W_L = density of product (lb/gal); 7.4 to 8.0 lb/gal assumed as typical range for volatile organic liquids

D = tank diameter, ft

N_C = number of columns

= 0, there are no columns in external floating roof tanks

F_C = effective column diameter, ft

= 0, there are no columns

K_S = seal factor, lb/-mole/(ft[mi/h])

v = average windspeed for the tank site, mi/h

n = seal windspeed exponent, dimensionless

P^* = the vapor pressure function, dimensionless;

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

P = the true vapor pressure of the materials stored, psia

P_A = atmospheric pressure, psia = 14.7

M_V = molecular weight of product vapor, lb/lb-mol

K_C = product factor, dimensionless

F_F = the total deck fitting loss factor, lb/mol/yr

$$= \sum_{i=1}^{n_f} (N_{F_i} K_{F_i}) = [(N_{F_1} K_{F_1}) + (N_{F_2} K_{F_2}) + \ldots + (N_{F_{n_f}} K_{F_{n_f}})]$$

where:

N_{F_i} = number of fittings of a particular type, dimensionless. N_{F_i} is determined for the specific tank or estimated from Tables A-8, A-9, or A-10

K_{F_i} = roof fitting loss factor for a particular type of fitting, lb-mol/yr. K_{F_i} is determined for each fitting type from Table A-8 or Figures A-10 through A-18.

n_f = number of different types of fittings, dimensionless = 3

4. Identify parameters to be calculated or determined from tables

In this example, the following parameters are not specified: W_L, F_F, C_F, K_S, v, n, P, P*, M_V, and K_C. Some typical assumptions that can be made are as follows:

v = average windspeed for the tank site = 10 mi/h

K_C = 1.0 for volatile organic liquids

C_F = 0.0015 bbl/10^3 ft^2 for tanks with light rust (from Table A-7)

K_S = 0.8 (from Table A-5)

n = 1.2 (from Table A-5)

F_F, W_L, P, P*, and M_V still need to be calculated.

F_F is estimated by calculating the individual K_{F_i} and N_{F_i} for each of the three types of roof fittings used in this example. For the ungasketed access hatches with unbolted covers, the K_f value can be calculated using information in Table A-8. For this fitting, K_{fa} = 2.7, K_{fb} = 7.1, and m = 1. There is normally one access hatch. So,

$$K_{F_{access\ hatch}} = K_{fa}+K_{fb}v^m$$

$$= 2.7+(7.1)(10)^1$$

$$= 73.7 \text{ lb-mol/yr}$$

$$K_{F_{access\ hatch}} = 1$$

$$N_{F_{access\ hatch}} = 1$$

The number of vacuum breakers can be taken from Table A-9. For tanks with a diameter of 20 feet and a pontoon roof, the number of vacuum breakers is one. Figure A-15 gives a value of 31 lb-mol/yr for weighted mechanical action, ungasketed vacuum breakers when the average windspeed is 10 miles per hour. So,

N_F vacuum breaker = 1

$$K_{F_{vacuum\ breaker}} = 31 \text{ lb-mol/yr}$$

For the ungasketed gauge hatch/sample wells with weighted mechanical actuation, Table A-8 indicates that tanks normally have only one. Figure A-14 gives $K_F$gauge hatch/sample well as 25 lb-mol/yr for a wind speed of 10 miles per hour.

$K_{F_{\text{gauge hatch/sample well}}}$ = 25 lb-mol/yr

$N_{F_{\text{gauge hatch/samples well}}}$ = 1

F_F can be calculated as:

$$= \sum_{i=1}^{3} (K_{F_i})(N_{F_i})$$

$$= (73.7)(1)+(31)(1)+(25)(1)$$

$$= 129.7 \text{ lb-mol/yr}$$

5. Calculate mole fractions in the liquid

The mole fractions of components in the liquid must be calculated in order to estimate the vapor pressure of the liquid using Raoult's Law. For this example, the weight fractions (given as 75 percent benzene, 15 percent toluene, and 10 percent cyclohexane) of the mixture must be converted to mole fractions. First, assume that there are 1,000 lb of liquid mixture. Using this assumption, the mole fractions calculated will be valid no matter how many pounds of liquid actually are present. The amount (pounds) of each component is equal to the weight fraction times 1,000:

Component	Weight fractionx1,000 lb =	$Pounds_i$ ÷	M_i, lb/ lb-moles =	Moles	Mole fraction
Benzene	0.75	750	78.1	9.603	0.773
Toluene	0.15	150	92.1	1.629	0.131
Cyclohexane	0.10	100	84.2	1.188	0.096
	1.00	1,000		12.420	1.000

For example, the mole fraction of benzene in the liquid is 9.603/12.420 = 0.773.

6. Calculate partial pressures and total vapor pressure of the liquid

The vapor pressure of each component at 70°F can be taken from Table A-2. Since Raoult's Law is assumed to apply in this example, the partial pressure of each component is the liquid mole fraction (x_i) times the vapor pressure of the component (P_i).

Component	P_i at 70°F X	x_i	= $P_{partial}$
Benzene	1.5	0.773	1.16
Toluene	0.4	0.131	0.0524
Cyclohexane	1.6	0.096	0.154
		1.00	1.37

The vapor pressure of the mixture is estimated to be 1.37 psia.

7. Calculate mole fractions in the vapor

The mole fractions of the vapor phase are based upon the partial pressure that each component exerts (calculated in Step 6).

The total vapor pressure of the mixture is 1.37 psia. So for benzene:

$$y_{benzene} = \frac{P_{partial}}{P_{total}} = \frac{1.16}{1.37} = 0.847$$

where:

$y_{benzene}$ = mole fraction of benzene in the vapor
$P_{partial}$ = partial pressure of benzene in the vapor, psia

P_{total} = total vapor pressure of the mixture, psia

Similarly,

$y_{toluene}$ = 0.0524/1.37 = 0.0382

$y_{cyclohexane}$ = 0.154/1.37 = 0.112

The vapor phase mole fractions sum to 1.0.

8. Calculate molecular weight of the vapor

The molecular weight of the vapor is dependent upon the mole fractions of the components in the vapor.

$$M_V = \Sigma M_i y_i$$

where:

M_v = molecular weight of the vapor

M_i = molecular weight of the component

y_i = mole fraction of component in the vapor

Component	M_i	x y_i	= $(M_i)(y_i)$
Benzene	78.1	0.847	66.151
Toluene	92.1	0.0382	3.518
Cyclohexane	84.2	0.112	9.430
		1.00	79.1

The molecular weight of the vapor is 79.1 lb/lb-mol.

9. Calculate weight fractions of the vapor

The weight fractions of the vapor are needed to calculate the amount (in pounds) of each component emitted from the tank. The weight fractions are related to the mole fractions calculated in Step 7. First, assume that there are 100 moles of vapor present. Using this assumption, the weight fractions calculated will be valid no matter how many moles actually are present.

Component	Mole fraction$_i$x100 mole =	No. of moles$_i$ x	M_i, lb/ lb-mole =	Pounds$_i$	Weight fraction
Benzene	0.847	84.7	78.1	6,615	0.836
Toluene	0.382	3.82	92.1	351.8	0.0445
Cyclohexane	0.112	11.2	84.2	943.0	0.119
	1.00	100		7,910	1.00

The weight fraction of each component is the pounds of that component divided by the total pounds of the mixture. For example, the weight fraction of benzene is 6,615/7,910 = 0.836.

10. Calculate total VOC emitted from the tank

The total VOC emitted from the tank is calculated using the equations identified in Step 3 and the parameters calculated in Steps 4 through 9.

$$L_T = L_{WD}+L_R+L_{RF}$$

$$L_{WD} = 0.943\ QCW_L/D[1+N_CF_C/D]$$

where:

Q = 100,000 galx10 turnovers/yr (given)

= 1,000,000 galx2.381 bbl/100 gal

Q = 23,810 bbl/yr

C_F = 0.0015 bbl/10^3 ft^2 (from Table A-5)

W_L = 1/[Σ (wt fraction in liquid)/(liquid density from Table A-2)]

= 1/[(0.75/7.4)+(0.15/7.3)+(0.10/6.5)]

= 1/(0.101+0.0205+0.0154)

= 1/0.1373

= 7.3 lb/gal

(A density range of 7.4 to 8.0 lb/gal is typical for volatile organic liquids.)

D = 20 ft (given)

N_C = 0 (given)

F_C = not applicable

$$L_{WD} = 0.943\ QC_FW_L/D[1+\frac{N_CF_C}{D}]$$

L_{WD} = [0.943(23,810)(0.0015)(7.3)/20][1+0/20]

L_{WD} = 12.3 lb of VOC/yr

$L_R = K_Sv^nP^*DM_VK_C$

K_S = 0.8 (from Step 3)

v = 10 mi/h (from Step 4)

n = 1.2 (from Step 4)

P = 1.4 psia (from Step 6)

$$P^* = \frac{\frac{1.4}{14.7}}{(1+[1-\frac{1.4}{14.7}]^{0.5})^2} \text{ (formula from Step 3)}$$

P^* = 0.0250

M_V = 79.1 lb/lb-mol (from Step 8)

$L_R = (0.8)(10^{1.2})(0.0250)(20)(79.1)(1.0)$

L_R = 501 lb of VOC/yr

$L_{RF} = F_FP^*M_VK_C$

where:

F_F = 129.7 lb-mol/yr (from Step 4)

P^* = 0.025

M_V = 79.1 lb/lb-mol

K_C = 1.0 (from Step 4)

L_F = (129.7) (0.025)(79.1)(1.0)

L_F = 256 lb/yr of VOC emitted

$L_T = L_{WD}+L_R+L_F$

L_T = 12.3+501+256

L_T = 770 lb/yr of VOC emitted from tank

11. Calculate amount of each component emitted from the tank

The amount of each component emitted is the weight fraction of that component in the vapor (calculated in Step 9) times the total amount of VOC emitted from the tank.

Component	Weight fraction x770 lb/yr =	Pounds emitted/yr
Benzene	0.836	644
Toluene	0.0445	34.3
Cyclohexane	0.119	91.6
	1.00	770

For benzene,

$$\frac{0.836 \text{ lb of benzene}}{1.0 \text{ lb of VOC}} \times 770 \text{ lb/yr of VOC} = 644 \text{ lb/yr of benzene emitted}$$

B.3 GASOLINE IN AN INTERNAL FLOATING ROOF TANK

Determine emissions of product from a 1,000,000-gallon, internal floating roof tank containing gasoline (RVP 13). The yearly average temperature in the area is 60°F. The annual number of turnovers for the tank is 50. The tank is 70 ft in diameter and 35 ft high and is equipped with a liquid-mounted primary seal plus a secondary seal. The tank's deck is welded and equipped with the following: (1) two access hatches with an unbolted, ungasketed cover; (2) an automatic gauge float well with an unbolted, ungasketed cover; (3) a pipe column well with a flexible fabric sleeve seal; (4) a sliding-cover, gasketed ladder well; (5) a fixed roof leg; (6) a slotted sample pipe well with a gasketed sliding cover; and (7) a weighted, gasketed vacuum breaker.

<u>Solution:</u>

1. <u>Determine tank type</u>

The following information must be known about the tank in order to use the internal floating roof equations:

--the number of columns
--the effective column diameter
--the system seal description (vapor, liquid mounted; primary or secondary seal)
--the deck fitting types and the deck seam length

Some of this information depends on specific construction details, which may not be known. In these instances, approximate values are provided for use.

2. <u>Determine estimating methodology</u>

Gasoline consists of many organic compounds, all of which are miscible in each other, which form a homogenous mixture. The tank emission rate will be based on the properties of RVP 13 gasoline. Since vapor pressure data have already been compiled, Raoult's Law will not be used. The molecular weight of gasoline also will be taken from a table and will not be calculated. Weight fractions of components will be assumed to be available from a VOC species manual (see Reference 14).

3. <u>Select equations to be used</u>

$$L_T = L_{WD} + L_R + L_F + L_D$$

$$L_{WD} = \frac{(0.943)QC_FW_L}{D}\left(1 + \frac{N_CF_C}{D}\right)$$

$$L_R = K_Sv^nP^*DM_VK_C$$

$$L_F = F_FP^*M_VK_C$$

$$L_D = K_DS_DD^2P^*M_VK_C$$

where:

L_T = total loss, lb/yr

L_{WD} = withdrawal loss, lb/yr

L_R = rim seal loss, lb/yr

L_F = deck fitting loss, lb/yr

L_D = deck seam loss, lb/yr

For this example,

Q = product average throughput, bbl/yr
tank capacity (bbl/turnover)xturnovers/yr

C_F = product withdrawal shell clingage factor, bbl/10^3 ft^2

W_L = density of liquid, lb/gal

D = tank diameter, ft

N_C = number of columns, dimensionless

F_C = effective column diameter, ft

K_S = seal factor, lb-mole/[ft [mi/h]^n]

v = average wind speed for the tank site, mi/h

n = seal windspeed exponent, dimensionless

M_V = the average molecular weight of the product vapor, lb/lb-mol

K_C = the product factor, dimensionless

P* = the vapor pressure function, dimensionless

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

P = the vapor pressure of the material stored, psia

P_A = average atmospheric pressure at tank location, psia

F_F = the total deck fitting loss factor, lb-mol/yr

$$= \sum_{i=1}^{n_f}(N_{F_i}K_{F_i}) = [(N_{F_1}K_{F_1})+(N_{F_2}K_{F_2})+ \ . \ . \ . \ +(N_{F_{n_f}}K_{F_{n_f}})]$$

where:

N_{F_i} = number of fittings of a particular type (dimensionless). N_{F_i} is determined for the specific tank or estimated from Table A-11.

K_{F_i} = deck fitting loss factor for a particular type of fitting, lb-mol/yr. K_{F_i} is determined for each fitting type from Table A-11.

n_f = number of different types of fittings, dimensionless

K_D = the deck seam loss factor, lb-mol/ft yr

= 0.34 for nonwelded roofs

= 0 for welded decks

S_D = deck seam length factor, ft/ft^2

$$= \frac{L_{seam}}{A_{deck}}$$

where:

L_{seam} = total length of deck seams, ft

A_{deck} = area of deck, ft^2 = $\pi D^2/4$

4. <u>Identify parameters to be calculated or determined from tables</u>

In this example, the following parameters are <u>not</u> specified: N_C, F_C, P, M_V, K_S, v, n, P*, K_C, F_F, K_D, and S_D. The density of the liquid (W_L) and the vapor pressure of the liquid (P) can be read from tables and do not need to be calculated. Also, the weight fractions of components in the vapor can be obtained from speciation manuals. Therefore, several steps required in preceeding examples will not be required in this example. In each case, if a step is not required, the reason is presented.

The following parameters can be obtained from tables or assumptions:

K_C = 1.0 (for volatile organic liquids)

N_C = 1 (from Table A-12)

F_C = 1.0 (assumed)

K_S = 1.6 (from Table A-5)

P = 6.9 psia (from Table A-2)

M_V = 62 lb/lb-mol (from Table A-2)

W_L = 5.6 lb/gal (from Table A-2)

C_F = 0.0015 bbl/10^3 ft^2 (from Table A-7)

v = 10 mi/h (assumed)

n = 0 (from Table A-5)

K_D = 0 (for welded roofs)

S_D = 0.2 ft/ft^2 (from Table A-13)

F_F = values taken from Table A-11

$= \sum (K_{F_i})(N_{F_i})$

$= (25)(2)+(28)(1)+(10)(1)+(56)(1)+0[5+\frac{70}{10}+\frac{70^2}{600}]+(44)(1)+(0.7)(1)$

= 188.7 lb-mol/yr

$$P^* = \frac{\frac{P}{P_A}}{[1+(1-\frac{P}{P_A})^{0.5}]^2}$$

$$= \frac{\frac{6.9}{14.7}}{[1+(1-\frac{6.9}{14.7})^{0.5}]^2}$$

= 0.157

5. Calculate mole fractions in the liquid

This step is not required because liquid mole fractions are only used to calculate liquid vapor pressure, which is given in this example.

6. Calculate partial pressures and total vapor pressure of the liquid

This step is not required because the vapor pressure of gasoline is given.

7. Calculate mole fractions in the vapor

This step is not required because vapor mole fractions are needed to calculate the weight fractions and the molecular weight of the vapor, which are already specified.

8. Calculate molecular weight of the vapor

This step is not required because the molecular weight of gasoline vapor is already specified.

9. Calculate weight fractions of the vapor

The weight fractions of gasoline vapor can be obtained from a VOC speciation manual.

10. Calculate total VOC emitted from the tank

The total VOC emitted from the tank is calculated using the equations identified in Step 3 and the parameters specified in Step 4.

$$L_T = L_{WD}+L_R+L_F+L_D$$

$$L_{WD} = \frac{(0.943)QC_FW_L}{D}(1+\frac{N_CF_C}{D})$$

where:

$Q = (1{,}000{,}000\ gal)x(50\ turnovers/yr)$
$= (50{,}000{,}000\ gal)x(2.381\ bbl/100\ gal)$
$= 1{,}190{,}500\ bbl/yr$
$C_F = 0.0015\ bbl/10^3\ ft^2$
$W_L = 5.6\ lb/gal$
$D = 70\ ft$
$N_C = 1$
$F_C = 1$

$$L_{WD} = \frac{(0.943)(1{,}190{,}500)(0.0015)(5.6)}{(70)}(1+\frac{(1)(1)}{70})$$

$L_{WD} = 136.6$ lb/yr of VOC emitted

$$L_R = K_SDv^nP^*M_VK_C$$

where:

$K_S = 1.6$
$v = 10\ mi/h$
$n = 0$
$P^* = 0.157$
$D = 70\ ft$

M_V = 62 lb/lb-mol

K_C = 1.0

$L_R = (1.6)(10^0)(0.157)(70)(62)(1.0)$

L_R = 1,090 lb/yr of VOC emitted

$L_F = F_F P^* M_V K_C$

where:

F_F = 235.5 lb-mol/yr

P^* = 0.157

M_V = 62 lb/lb-mol

K_C = 1.0

$L_F = (188.7)(0.157)(62)(1.0)$

L_F = 1,837 lb/yr of VOC emitted

$L_D = K_D S_D D^2 P^* M_V K_C$

where:

K_D = 0

S_D = 0.2

D = 70 ft

P^* = 0.157

M_V = 62 lb/lb-mol

K_C = 1.0

$L_D = (0.0)(0.2)(70)^2(0.157)(62)(1.0)$

L_D = 0 lb/yr of VOC

$L_T = L_{WD} + L_R + L_F + L_D$

$L_T = 136.6 + 1{,}090 + 1{,}837 + 0$

L_T = 3,064 lb/yr of VOC emitted from the tank

11. <u>Calculate amount of each component emitted from the tank</u>

The amount of each component emitted is the weight fraction of that component in the vapor (obtained from a VOC species data manual and shown in Table B-2) times the total amount of VOC emitted from the tank. Table B-2 shows the amount emitted for each component in this example.

TABLE B-2. EMISSIONS FOR EXAMPLE 3

Constituent	Weight percent in vapor	x3,064 lb/yr =	Pounds emitted/yr
Air toxics			
Benzene	0.77		23.5
Toluene	0.66		20.2
Ethylbenzene	0.04		1.23
o-xylene	0.05		1.53
Nontoxics			
Isomers of pentane	26.78		821
N-butane	22.95		703
Iso-butane	9.83		301
N-pentane	8.56		262
Isomers of hexane	4.78		146
3-methyl pentane	2.34		71.7
Hexane	1.84		56.4
Others	21.40		656
	100		3,064

B.4 CHEMICAL MIXTURE IN A HORIZONTAL FIXED ROOF TANK

Determine the yearly emission rate of product and of each component from a horizontal above ground, fixed roof storage tank containing (for every 1,750 lb of liquid mixture) 1,600 lb of benzene, 100 lb of toluene, and 50 lb of cyclohexane. The tank is not heated and the average yearly ambient temperature of the area is 67.5°F. The tank is 10 ft in diameter and 17 ft long and the roof and shell are painted aluminum. The tank volume is 10,000 gallons. The number of turnovers per year for the tank is three (i.e., the throughput of the tank is 30,000 gal/yr).

Solution:

1. Determine tank type

The tank is a horizontal, fixed roof storage tank.

2. Determine estimating methodology

The product consists of three organic liquids, all of which are miscible in each other and make a homogenous mixture if the material is well mixed. The tank emission rate will be based upon the properties of the mixture. Since the fixed roof equations were developed for vertical tanks, the diameter and height of the tank will need to be calculated. The components have similar structures and molecular weights, so Raoult's Law will be assumed to apply.

3. Select equations to be used

For a horizontal, fixed roof storage tank, the following equations apply:

$$L_T = L_B + L_W$$

$$L_B = 2.26X10^{-2} M_V \left(\frac{P}{P_A - P}\right)^{0.68} D^{1.73} H^{0.51} \Delta T^{0.5} F_P C K_C$$

$$L_W = 2.40x10^{-5} M_V P V N K_N K_C$$

where:

L_T = total loss, lb/yr of VOC

L_B = breathing loss, lb/yr of VOC

L_W = working loss, lb/yr of VOC

M_V = molecular weight of product vapor, lb/lb-mol

P = true vapor pressure of product, psia

P_A = atmospheric pressure, psia

D = tank diameter, ft

H = average vapor space height, ft

ΔT = average diurnal temperature change, °F

F_P = paint factor (dimensionless); see Table A-1;

C = tank diameter factor (dimensionless):

for diameter ≥30 feet, C = 1

for diameter <30 feet,

$C = 0.0771 (D)-0.0013(D^2)-0.1334$

K_C = product factor (dimensionless) = 1.0 for volatile organic liquids, 0.65 for crude oil

V = tank capacity, gal

N = number of turnovers per year (dimensionless)

$= \frac{\text{throughput, gal/yr}}{\text{tank capacity, gal}}$

K_N = turnover factor (dimensionless):

for turnovers >36, $K_N = \frac{180+N}{6N}$

for turnovers ≤36, $K_N = 1$

4. Identify parameters to be calculated or determined from tables

In this example, the following parameters are not specified: M_V, P, ΔT, K_C, P_A, C, H, and F_P. Some typical assumptions that can be made are:

F_P = 1.2 for aluminum (specular) paint on roof and shell (see Table A-1)

ΔT = 20°F

P_A = atmospheric pressure = 14.7 psia

K_C = 1.0 for volatile organic liquids

Since the emission estimating equations were developed for vertical tanks, some of the horizontal tank parameters must be modified before using the equations. First, assume that the tank is one-half filled. The surface area of the liquid in this case is approximately equal to the length of the tank times the diameter of the tank. In this case, the surface area is 17x10 = 170 ft^2. Next, assume that this area represents a circle, i.e., that the liquid is in an upright cylinder. Solving for diameter ($A = 170\ ft^2 = \pi D^2/4$) yields a diameter of 14.7 ft. Thus, a value of 14.7 ft for D should be used in the equations. Since the tank is assumed to be one-half full, the vapor space is equal to one-half the diameter of the tank. Therefore, a value of 10 ftx1/2 = 5 ft for H should be used in the equations.

The tank diameter factor (C) is calculated using a diameter of 14.7 ft.

$$C = 0.0771(14.7)-0.0013(14.7)^2-0.1334$$

$$C = 0.719$$

If this tank were located underground, then the breathing losses could be assumed to be negligible because the diurnal temperature change (ΔT) would be close to zero.

The vapor pressure (P) of the liquid and the molecular weight of the vapor (M_V) still need to be calculated.

5. Calculate mole fractions in the liquid

The mole fractions of components in the liquid must be calculated in order to calculate the vapor pressure of the liquid using Raoult's Law.

The molecular weight for each component (M_i) can be read from Table A-2.

Component	Amount, lb	÷	M_i	=	Moles	x_i
Benzene	1,600		78.1		20.5	0.92
Toluene	100		92.1		1.09	0.049
Cyclohexane	50		84.2		0.594	0.027
Total	1,750				22.2	1.00

For benzene,

$$x_{benzene} = moles_{benzene}/\text{total moles} = 20.5/22.2 = 0.92.$$

6. Calculate partial pressures and total vapor pressure of the liquid

The vapor pressure of the mixture may be found by first obtaining the vapor pressures of each component from Table A-2. In this example, the storage tank is painted aluminum. Therefore, the temperature of the stored liquid must be adjusted using Table A-3. Table A-3 indicates that the average yearly temperature must be adjusted by 2.5 degrees to account for the aluminum tank. Therefore, vapor pressure information should be taken from Table A-2 at 67.5+2.5 = 70°F.

Component	Vapor pressure at 70°F, psia
Benzene	1.5
Toluene	0.4
Cyclohexane	1.6

According to Raoult's Law, the partial pressure of a component is the product of its pure vapor pressure and its liquid mole fraction.

Component	P_i at 70°F	X	x_i	=	$P_{partial}$
Benzene	1.5		0.92		1.38
Toluene	0.4		0.049		0.0196
Cyclohexane	1.6		0.027		0.0432
			1.00		1.44

The vapor pressure of the mixture is 1.4 psia.

7. Calculate mole fractions in the vapor

The mole fractions of the vapor phase are based upon the partial pressure that each component exerts (calculated in Step 6).

The total vapor pressure of the mixture is 1.44 psia; so, for benzene:

$$y_{benzene} = \frac{P_{partial}}{P_T} = \frac{1.38}{1.44} = 0.958$$

where:

$y_{benzene}$ = mole fraction of benzene in the vapor

$P_{partial}$ = partial pressure of benzene, psia

P_T = total vapor pressure of the mixture, psia

Similarly, for toluene and cyclohexane,

$$y_{toluene} = \frac{0.0196}{1.44} = 0.0136$$

$$y_{cyclohexane} = \frac{0.0432}{1.44} = 0.03$$

The vapor phase mole fractions sum to 1.0.

8. Calculate molecular weight of the vapor

The molecular weight of the vapor is dependent upon the mole fractions of the components in the vapor.

$$M_V = \Sigma M_i y_i$$

where:

M_V = molecular weight of the vapor, lb/lb-mole

M_i = molecular weight of the component, lb/lb-mole

y_i = mole fraction of the component in the vapor

Component	M_i	X	y_i	=	$(M_i)(y_i)$
Benzene	78.1		0.958		74.82
Toluene	92.1		0.0136		1.253
Cyclohexane	84.2		0.03		2.526
			1.00		78.6

The molecular weight of the vapor is 78.6 lb/lb-mol.

9. Calculate weight fractions of the vapor

The weight fractions of the vapor are needed to calculate the amount of each component emitted from the tank. The weight fractions are related to the previously calculated mole fractions. First, assume that there are 100 moles of vapor present. Using this assumption, the weight fractions calculated will be valid no matter how many moles actually are present.

Component	No. of moles	X	M_i	=	$Pounds_i$	Weight fraction
Benzene	958		78.1		74,820	0.952
Toluene	13.6		92.1		1,253	0.0159
Cyclohexane	30.0		84.2		2,526	0.0321
	1,000				78,599	1.00

The weight fraction of each component is the pounds of that component divided by the total pounds of the mixture. For example,

$$\text{weight fraction}_{\text{benzene}} = \frac{74,820}{78,599} = 0.952.$$

10. Calculate total VOC emitted from the tank

The total VOC emitted from the tank is calculated using the equations identified in Step 3 and the parameters calculated in Steps 4 through 9.

$$L_T = L_B + L_W$$

where:

L_T = total loss, lb/yr of VOC

L_B = total breathing loss, lb/yr of VOC

L_W = total working loss, lb/yr of VOC

$$L_B = 2.26\times10^{-2} M_V \left(\frac{P}{P_A - P}\right)^{0.68} D^{1.73} H^{0.51} \Delta T^{0.5} F_P C K_C$$

where:

M_V = 78.6 lb/lb-mol (from Step 8)

P = 1.4 psia (from Step 6)

P_A = 14.7 psia (from Step 4)

D = 14.7 ft (from Step 4)

H = 5 ft (from Step 4)

ΔT = 20°F (from Step 4)

F_P = 1.2 (from Step 4)

C = 0.719 (from Step 4)

K_C = 1 (from Step 4)

$$L_B = 2.26\times10^{-2}(78.6)\left(\frac{1.4}{14.7-1.4}\right)^{0.68}(14.7)^{1.73}(5)^{0.51}(20)^{0.5}(1.2)(0.719)(1)$$

L_B = 352 lb/yr of VOC emitted

$$L_W = 2.40\times10^{-5}\ M_V P V N K_N K_C$$

where:

M_V = 78.6 lb/lb-mol (from Step 8)

P = 1.4 psia (from Step 6)

V = 10,000 gal (given)

N = 3 (given)

K_N = 1 (from Step 3)

K_C = 1 (from Step 4)

$L_W = 2.40\times10^{-5}(78.6)(1.4)(10{,}000)(3)(1)(1)$

L_W = 79.2 lb/yr of VOC

L_T = 352+79.2

L_T = 431 lb/yr of VOC emitted from the tank

11. Calculate amount of each component emitted from the tank

The amount of each component emitted is the weight fraction of that component in the vapor (calculated in Step 9) times the amount of total VOC emitted.

Component	Weight fraction	x431 lb/yr =	Pounds emitted/yr
Benzene	0.952		410
Toluene	0.0159		6.85
Cyclohexane	0.0321		13.8
	1.00		431

For benzene,

$$\frac{0.948 \text{ lb of benzene}}{1 \text{ lb of VOC}} \times 431 \text{ lb/yr of VOC} = 410 \text{ lb/yr of benzene emitted}$$

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

To assist groups interested in inventorying air emissions of potentially toxic substances, EPA is preparing a series of documents that compiles available information on sources and emissions of toxic substances. This document deals specifically with methods to estimate air toxics emissions from organic liquid storage tanks. Its intended audience includes Federal, State, and local air pollution personnel and others interested in making estimates of toxic air pollutants emitted from organic liquid storage tanks.

This document presents equations for estimating air toxics emissions from organic liquid storage tanks and demonstrates through examples how to use the equations. Information is also provided on storage tanks typically associated with source categories.

17. KEY WORDS AND DOCUMENT ANALYSIS

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