Report to the Joint Standing Committee on the Environment and Natural Resources

Measurement and Control of Emissions from Aboveground Petroleum Storage Tanks

January 1, 2021

MAINE DEPARTMENT OF ENVIRONMENTAL PROTECTION
17 State House Station | Augusta, Maine 04333-0017
www.maine.gov/dep

Contents

I. Introduction

In the second regular session of 2020, the 129th Maine Legislature passed L.D. 1915: "Resolve, Directing the Department of Environmental Protection To Evaluate Emissions from Aboveground Petroleum Storage Tanks." The resolve directs the Department of Environmental Protection (Department) to study methods to measure and estimate air emissions from aboveground petroleum storage tanks, to study methods to control odor and other air emissions from emission sources at oil terminal facilities including emissions from aboveground petroleum storage tanks, loading racks, and vessel offloading, to identify methods or programs for assisting municipalities in the use and application of mobile air quality monitoring devices, and to report its findings to the joint standing committee of the Legislature having jurisdiction over environment and natural resources matters (Committee) by January 1, 2021.

Several Bureau of Air Quality staff were involved in conducting the requested studies over the past several months and in completing this report. Bureau of Air Quality staff consulted various resources, including reaching out to other state environmental agencies to conduct these studies. In accordance with the resolve, this report contains the Department's findings. The report also contains the Department's recommendations for consideration by the Committee. The Department is available to present a summary of this report to the Committee and answer any questions.

II. Description of Sources

A. Facilities Included in Study

This study focused on facilities which store and distribute petroleum products on a large scale, referred to throughout this document as petroleum storage facilities[1]. In general, a petroleum storage facility consists of storage tanks and a system for receiving and distributing the stored product. The storage tanks may be of various sizes and configurations. The stored products may be received and/or distributed by pipeline, ship, rail, or truck.

Maine has 11 existing petroleum storage facilities with air emission licenses (Appendix A). Three of these licensed facilities are categorized as major sources[2] of criteria pollutants including volatile organic compounds (VOC). The remaining facilities operate with license constraints that limit emissions to 50 tons/year of VOC or less, classifying these facilities as synthetic minor sources[3]. In some cases, facilities have accepted license restrictions significantly less than the 50 tons/year major source threshold. Maine has no petroleum storage facilities classified as major sources of hazardous air pollutants[4] (HAP), defined as having the potential to emit greater than 10 tons/year of any one HAP or 25 tons/year for all HAP combined[5].

Eight of Maine's licensed facilities are considered bulk gasoline terminals, since their gasoline throughput is potentially greater than 20,000 gallons per day[6]. These facilities may store and distribute other petroleum products in addition to gasoline. Maine has no licensed bulk gasoline plants, which are petroleum storage facilities with gasoline throughputs less than 20,000 gallons per day. The three remaining facilities store and distribute petroleum products other than gasoline (e.g., distillate fuel, asphalt, etc.).

In addition to the petroleum storage facilities addressed in this study, there are smaller bulk storage facilities located throughout the state. These include local storage and distribution tanks associated with home heating oil providers; fuel oil tanks located at industrial and electrical generating facilities; and asphalt tanks associated with hot-mix asphalt plants. These storage tanks were determined to be outside the scope of this study.

[1] See Section III.A for regulatory references.
[2] 06-096 C.M.R. ch. 100, §125(C)
[3] "Synthetic minor source" means a source that otherwise has the potential to emit pollutants in amounts that are at or above the thresholds for major sources but has taken an enforceable license restriction so that its potential to emit is less than those major source thresholds.
[4] Compounds which are considered a hazardous air pollutant are defined by Section 112(b) of the Clean Air Act.
[5] 06-096 C.M.R. ch. 100, §125(A)
[6] 06-096 C.M.R. ch. 100, §24

B. Pollutants Studied

Air emissions from petroleum storage facilities occur when the product being stored evaporates, either directly into the atmosphere or into a vapor space inside a tank that is later released to the atmosphere.

The main pollutant of concern from petroleum storage facilities is VOC. VOC comprise a large class of carbon-containing compounds which participate in atmospheric photochemical reactions. A few compounds are specifically excluded from this definition, including carbon monoxide and carbon dioxide. VOC typically have high volatility, high vapor pressure[7], and low water solubility. This study focused on methods to estimate and control VOC emissions from petroleum storage facilities.

HAP, also known as toxic air pollutants or air toxics, are those pollutants that are known or suspected to cause cancer or to have other serious health effects, such as reproductive system effects or birth defects, or that are known or suspected to have adverse environmental effects[8]. Like emissions of VOC, emissions of HAP from petroleum storage facilities come from evaporative losses of the product being stored or transferred. Although not all HAP are VOC, the vast majority of HAP emissions from petroleum storage facilities are also VOC, and any control equipment that reduces emissions of VOC also reduces HAP from those facilities. Therefore, throughout this document, VOC has been used as a surrogate for all regulated air pollutants from petroleum storage facilities, including HAP.

Emissions from petroleum storage facilities may or may not result in a detectable odor. Available methods for controlling odor from these facilities were also addressed in this study.

C. Products Stored

The products stored in the petroleum storage facilities studied included products of various classifications and properties, primarily gasoline, distillate fuel, residual fuel, liquid asphalt, and crude oil.

1. Crude Oil

   Crude oil is a naturally occurring, unprocessed petroleum product comprised of a mixture of liquid hydrocarbons and includes small amounts of nitrogen, sulfur, and

[7] Vapor pressure is defined as the pressure exerted by a vapor in thermodynamic equilibrium with its liquid phase at a given temperature. It relates to the tendency of particles to escape from the liquid. A substance with a higher vapor pressure is considered more volatile.

[8] https://www.epa.gov/haps/what-are-hazardous-air-pollutants

oxygen. Gasoline, distillate fuels, residual fuels, and liquid asphalt are produced from the fractional distillation of crude oil.

2. Gasoline

Gasoline is a spark-ignition engine fuel which may or may not be blended with oxygenates, such as alcohols and ethers. The characteristics and requirements of gasoline are described in *Standard Specification for Automotive Spark-Ignition Engine Fuel*, ASTM[9] D4814-20. Gasoline typically has a true vapor pressure of greater than 3.5 pounds per square inch absolute (psia) and less than 11.0 psia[10] at 60 °F. For the purposes of this study, aviation gasoline is included in this category of product.

3. Distillate Fuels

The term "distillate fuels" refers to a group of petroleum products including kerosene, diesel fuel, #2 fuel oil, and home heating oil. This term encompasses all of the following:

- Fuel oil that complies with the specifications for fuel oil number 1 or 2, as defined by *Standard Specification for Fuel Oils*, ASTM D396-19a;
- Diesel fuel oil number 1 or 2, as defined in *Standard Specification for Diesel Fuel*, ASTM D975-19c;
- Kerosene, as defined in *Standard Specification for Kerosene*, ASTM D3699-19;
- Biodiesel, as defined in *Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels*, ASTM D6751-20; and
- Biodiesel blends, as defined in *Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20)*, ASTM D7467-20.

Distillate fuels are used in compression-ignition reciprocating internal combustion engines (i.e., diesel engines); combustion turbines; and residential, commercial, and industrial furnaces and boilers. Distillate fuel has a true vapor pressure of approximately 0.006 psia[11] at 60 °F. For the purposes of this report, jet fuel is considered a type of distillate fuel.

[9] ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes technical standards for a wide range of materials, products, systems, and services.
[10] EPA's *Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources* (AP-42), Table 7.1-2
[11] AP-42, Table 7.1-2

4. Residual Fuels

The term "residual fuels" refers to a group of dense petroleum products commonly referred to as "#6 fuel oil" or by the Navy specification "Bunker C." Residual fuels are the products that remain after distillation of crude oil. They include fuel oil that complies with the specifications for fuel oil number 4, 5, or 6 in *Standard Specification for Fuel Oils*, ASTM D396-19a. Viscosity, an important quality specification for residual fuel oil, is a measure of a liquid's resistance to flow. High-viscosity fuel oil is more difficult to pump and is therefore less desirable as a product. Oil refiners manage fuel oil viscosity either through processing or through blending in a material of lower viscosity. Material added to reduce the viscosity of residual fuel is called cutter stock. Common cutter stocks for fuel oil blending are light cycle oil (from the diesel-range product of crude oil refinement) and kerosene. These cutter stocks are significantly more valuable than the resulting fuel oil blend, so refiners work to minimize the amount of cutter stock in a finished blend while still producing on-specification fuel oil.[12] Such fuel blending usually is done by the refiner prior to transportation to petroleum storage facilities such as those in Maine.

Due to its physical properties, i.e., being a thick, black, sticky liquid, the true vapor pressure of #6 fuel oil is difficult to measure. Previous estimates assumed a true vapor pressure of 0.00004 psia at 60 °F. However, the #6 fuel oil currently on the market is typically blended with light cutter stock to improve characteristics such as viscosity and heat content. The true vapor pressure of #6 fuel oil is now estimated to be approximately 0.002 psia[13] at 60 °F.

Residual fuels have a high viscosity and must be stored at greater than 100 °F and heated to 200 °F – 300 °F before they can be effectively pumped through pipes. At cooler temperatures, they congeal into a semi-solid. True vapor pressure is an exponential function of temperature. The true vapor pressure of #6 fuel oil is 0.06 psia[14] at 200 °F and 0.38 psia at 300 °F.

Fuels referred to as #4 fuel oil or #5 fuel oil are typically a blend of #6 fuel oil with distillate fuel. Very little #4 fuel oil or #5 fuel oil is currently used in Maine, and the blending typically takes place just prior to delivery to the customer. As such, there are no #4 fuel oil or #5 fuel oil storage tanks of significant size in this state.

[12] https://www.mckinseyenergyinsights.com/resources/refinery-reference-desk/cutter-stock/#:~:text=Cutter%20stock%20is%20any%20stream%20that%20is%20blended,stock%20is%20commonly%20used%20in%20fuel%20oil%20blending.

[13] AP-42, Table 7.1-2

[14] AP-42, Table 7.1-2 and Equation 1-25

Residual fuels are typically used by large industrial or electrical generating boilers or to fuel engines on large ships.

5. Asphalt

Asphalt is a dense petroleum product which may occur naturally or be produced in the crude oil refining process. Similar to residual fuel, asphalt is comprised of the heavy remains left over from the distillation process and may have been blended with cutter stock to reduce the viscosity to meet product specifications. The vast majority of asphalt stored in Maine is used in road construction to bind aggregate particles to create asphalt concrete. It is extremely viscous and will not flow at ambient temperatures. Asphalt is stored at temperatures above 300 °F because it solidifies at temperatures below 250 °F.

Due to its physical properties, i.e., being a thick, black, sticky semi-solid, the true vapor pressure of asphalt is nearly impossible to measure. However, it is generally assumed to be lower than that of #6 fuel oil based on its position in the refinery process.

D. Emission Units

Petroleum storage facilities generally consist of a system for receiving product, tanks for storing product, and a system for distributing product. These facilities also include other equipment and processes which emit air pollutants, including but not limited to maintenance activities and combustion units for facility heating. There is potential to release VOC and/or odor at each point in the system. Following is a discussion of the different processes and pieces of equipment where emissions may occur.

1. Receiving Product

Petroleum product may be received at the petroleum storage facility by pipeline, ship (oil tanker), rail, or truck. In the case of ship, rail, or truck delivery, the product is pumped from the delivery vessel to a petroleum storage tank.

2. Product Storage

Petroleum storage tanks may be found in many configurations based primarily on volume, product stored, and age. The tanks included in this study ranged in capacity from 180 thousand gallons to over seven million gallons. All tanks included in this study were cylindrical, above-ground petroleum storage tanks with various roof configurations as appropriate for the stored material. Types of tank roofs will be discussed in more detail in Section III of this report. Depending on the product being stored, the tank may be heated or unheated; and uninsulated, partially insulated, or fully insulated.

3. Product Distribution

   Product distribution involves movement of the petroleum product out of the petroleum storage facility to the end user or to facilities where the product is marketed (e.g., gas stations). This study is limited to emissions that take place at bulk petroleum storage facilities and does not include emissions from on-road transportation, pipelines, marketing of petroleum products (e.g., gas stations, home heating oil vendors), or end-users (e.g., asphalt batch plants).

4. Miscellaneous Emissions

   Piping, Tank Landings, Tank Cleaning, Control Equipment

   In addition to the operations described above, emissions at petroleum storage facilities can also occur from facility piping, floating roof landings, tank cleaning, heating equipment, and control equipment.

   a. Facility Piping

      The pipes, fittings, and valves that transport liquid product and vapors throughout a petroleum storage facility can be a source of emissions, especially if this equipment is not kept in good repair.

   b. Floating Roof Landings

      Emissions from petroleum storage tanks vary depending on the product stored and the tank roof configurations. When using floating roof tanks (as described in Section III) the roof floats on the surface of the liquid product inside the tank and reduces evaporative losses during routine operations. However, floating roofs cannot be lowered all the way to the floor of the tank without preventing access to the inside of the tank for maintenance and inspection activities. Therefore, floating roof tanks have deck legs or hangers that prevent them from lowering beyond a certain point.

      When a floating roof tank is emptied beyond the point where the roof lands on its deck legs or hangers, the tank behaves as if it were a fixed roof tank with corresponding differences in emissions mechanisms. Therefore, the petroleum storage facility must keep records of every time the roof is “landed” in order to accurately estimate emissions from those periods.

c. Tank Cleaning

As part of routine or non-routine maintenance, a tank may occasionally need to be fully emptied and "degassed" or ventilated to allow personnel to enter the tank to perform repairs or maintenance. Tank cleaning includes the following phases:

(1) Pumpout

The tank roof will be landed (if a floating roof) and as much product as possible will be pumped out of the tank in the normal manner. Emissions from the pumpout are equivalent to regular product transfers. As the product is pumped out of the tank, fresh (ambient) air is drawn in to replace the volume.

(2) Standing Idle

After pumpout, the tank may remain in an idle condition for a period of time until the next steps occur. A pumpout does not remove all product from the bottom of the tank. Some amount of product, called liquid heel, will remain in the bottom of the tank. The amount of product depends on location of the pipe used to empty the tank. Emissions that occur during this period are accounted for the same as routine breathing losses from a fixed roof tank. (Breathing losses are discussed in Section III(B)(2)(a)(2).)

(3) Vapor Space Purge and Forced Ventilation

In order to provide a safe environment for repair and maintenance activities, the vapor space within the tank must be purged by fans or blowers either at the top of the tank or at a manhole or other fitting in the side of the tank.

The first exchange of air from the vapor space results in the highest emissions because the evacuated air is saturated with VOC from the product. This initial exchange is called the vapor space purge. A vapor space purge will occur each time the fans/blowers are started up after the tank has sat idle for a period of time without forced ventilation (e.g., sitting idle overnight).

After a vapor space purge, subsequent exchanges of air within the vapor space are referred to as forced ventilation. As long as some product remains in the tank, some portion of the volatile material will evaporate into the air being moved through the tank by forced ventilation. However, the concentration of VOC in the exhausted air stream will be less than in a vapor space purge since the evacuated air is not completely saturated with VOC.

(4) Remain Clean

Once the tank has been rendered clean and vapor-free, it may remain in the clean condition for some period of time. While forced ventilation may continue, if the liquid heel at the bottom of the tank has been completely removed, there are no further emissions.

(5) Refilling

As the tank is refilled, vapors are generated by the incoming product. This VOC-laden air is then expelled from the tank as it is displaced by the rising liquid level. For a fixed roof tank, the emissions are similar to normal working losses. For a floating roof tank, emissions are similar to working losses from a fixed roof tank until the level of the product reaches the roof and the roof is re-floated.

d. Heating Equipment

Tanks that store residual fuels or asphalt need to be heated to keep the product in a liquid, flowable form. Heat is provided to the tanks typically by boilers or furnaces that heat an intermediate liquid, usually a thermal oil, that is circulated through pipes that surround the tank. The boilers or furnaces used to provide this heat emit combustion byproducts, such as particulate matter, sulfur dioxide, nitrogen oxides, and carbon monoxide.

e. Control Equipment

Equipment used to control emissions from petroleum storage facilities may itself result in emissions of VOC or other pollutants depending on the type of control. For example, control equipment which destroys VOC by burning the vapors will result in emissions of combustion byproducts, such as particulate matter, sulfur dioxide, nitrogen oxides, and carbon monoxide.

III. Methods for Controlling Emissions

A. Resources Consulted

The following resources were consulted in researching the control options available for petroleum storage facilities.

1. State Regulations

Petroleum Liquid Storage Vapor Control, 06-096 C.M.R. ch. 111, addresses state requirements for fixed roof petroleum storage tanks larger than 39,000 gallons.

Bulk Terminal Petroleum Liquid Transfer Requirements, 06-096 C.M.R. ch. 112, addresses state requirements for bulk gasoline terminals with a daily gasoline throughput of 20,000 gallons or more. Maine has eight petroleum storage facilities in this category.

Major and Minor Source Air Emission License Regulation, 06-096 C.M.R. ch. 115, specifies who must obtain an air emission license, the information that must be submitted to apply for an air emission license, and the criteria for license approval. In order to receive a license, the applicant must control emissions from each unit to a level considered by the Department to represent Best Practical Treatment (BPT). BPT for existing emissions equipment means that method which controls or reduces emissions to the lowest possible level considering the existing state of technology, the effectiveness of available alternatives for reducing emissions, and the economic feasibility for the type of establishment involved. BPT for new sources and modifications requires a demonstration that emissions are receiving Best Available Control Technology (BACT). BACT is a top-down approach to selecting air emission controls considering economic, environmental, and energy impacts.

Reasonably Available Control Technology for Facilities That Emit Volatile Organic Compound (VOC-RACT), 06-096 C.M.R. ch. 134, establishes requirements for facilities that emit or have the potential to emit forty tons or more per year of VOC. Maine has nine petroleum storage facilities in this category.

2. Federal Regulations

The following federal regulations address requirements for specific categories of petroleum storage tanks:

- *Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced After June 11, 1973, and Prior to May 19, 1978*, 40 C.F.R. Part 60, Subpart K.

- *Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced After May 18, 1978, and Prior to July 23, 1984,* 40 C.F.R. Part 60, Subpart Ka.
- *Standards of Performance for Volatile Organic Liquid Storage Vessels (Including Petroleum Liquid Storage Vessels) for Which Construction, Reconstruction, or Modification Commenced After July 23, 1984,* 40 C.F.R. Part 60, Subpart Kb.
- *Standards of Performance for Bulk Gasoline Terminals*, 40 C.F.R. Part 60, Subpart XX, addresses requirements for loading racks constructed or modified after December 17, 1980.
- *National Emission Standards for Gasoline Distribution Facilities (Bulk Gasoline Terminals and Pipeline Breakout Stations)*, 40 C.F.R. Part 63, Subpart R, addresses requirements for loading racks, storage vessels, and equipment leaks at bulk gasoline terminals. However, this regulation only applies to facilities categorized as major sources of HAP, i.e., facilities with the potential to emit greater than 10 tons/year of any single HAP or 25 tons/year of all HAP combined. Maine has no petroleum storage facilities in this category.
- *National Emission Standards for Hazardous Air Pollutants for Source Category: Gasoline Distribution Bulk Terminals, Bulk Plants, and Pipeline Facilities*, 40 C.F.R. Part 63, Subpart BBBBBB, addresses requirements for area sources of HAP (i.e., facilities with potential HAP emissions less than major source levels).
- *National Emission Standards for Marine Tank Vessel Loading Operations*, 40 C.F.R. Part 63, Subpart Y, addresses requirements for the transferring of petroleum products to ships.

3. EPA's Compilation of Air Pollutant Emission Factors (AP-42)

The Department considered EPA's *Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources* (AP-42). Since 1972, AP-42 has been considered EPA's primary compilation of emission factor information. It contains emissions factors and process information for more than 200 air pollution source categories. A source category is a specific industry sector or group of similar emitting sources. Specifically, the Department considered information contained in AP-42, Chapter 5.2, *Transportation and Marketing of Petroleum Liquids* (July 2008) and Chapter 7.1, *Organic Liquid Storage Tanks* (March 2020). AP-42 provides a significant amount of information on control equipment and strategies in common use throughout the industry.

4. EPA Control Cost Manual

The Department referred to EPA's *Air Pollution Control Cost Manual (Sixth Edition),* *Section 3: VOC Controls* for descriptions and design considerations for various control devices.

5. RACT/BACT/LAER[15] Clearinghouse

The RACT/BACT/LAER Clearinghouse (RBLC) is an EPA database containing case-specific information on the "Best Available" air pollution technologies that have been required to reduce the emission of air pollutants from stationary sources (e.g., power plants, chemical plants, etc.). The information contained in the RBLC is provided to EPA by state and local permitting agencies.

The terms "RACT," "BACT," and "LAER" are acronyms for different program requirements under the new source review (NSR) permitting program. They represent different types of determinations regarding appropriate emission limits and control equipment for a particular facility or emissions unit. BACT and LAER are determined on a case-by-case basis, usually by state or local permitting agencies. EPA established the RBLC to provide a central database of air pollution technology information, including previous BACT and LAER determinations, to promote the sharing of information among permitting agencies and to aid in future case-by-case determinations.

The information in the RBLC is not limited to RACT, BACT, or LAER decisions. Noteworthy prevention and control technology decisions and information may be included even if they are not related to past RACT, BACT, or LAER decisions.

Control technologies included in the RBLC for petroleum storage facilities were considered as part of this report.

6. California South Coast Air Quality Management District Determinations

Similar to the RBLC, California's South Coast Air Quality Management District (South Coast AQMD) has a database[16] of BACT determinations searchable by equipment type. Control technologies included in South Coast AQMD's database for petroleum storage facilities were considered as part of this report.

7. Texas Best Available Control Technology Guidelines

The Texas Commission on Environmental Quality (Texas CEQ) posts on its website[17]

[15] RACT stands for Reasonably Available Control Technology; BACT stands for Best Available Control Technology; and LAER stands for Lowest Achievable Emission Rate. These represent different program requirements defined in federal regulations.
[16] http://www.aqmd.gov/home/permits/bact/guidelines/i---scaqmd-laer-bact
[17] https://www.tceq.texas.gov/permitting/air/nav/bact_index.html

guidelines for performing a BACT analysis for projects in that state. Their guidance document titled *Air Permit Reviewer Reference Guide, APDG 6110, Air Pollution Control, How to Conduct a Pollution Control Evaluation*, provides permit reviewers with a process to evaluate and determine air pollution control requirements.

Texas uses a three-tiered approach to evaluate BACT proposals in NSR permit applications. In Tier I, an applicant's BACT proposal is compared to the emission reduction performance levels accepted as BACT in recent NSR permit reviews for the same process and/or industry. The analysis only moves on to Tier II or Tier III if BACT requirements have not already been established for a particular process/industry or if there are compelling technical differences between the applicant's facility and others in the same industry. Therefore, if a Tier I BACT determination exists for a given process, that Tier I BACT is, by default, considered to be the most appropriate control.

There are Tier I BACT determinations[18] available for the following categories:

- Fixed roof tanks with capacities < 25 thousand gallons (Mgal) and true vapor pressure (TVP) < 0.5 pounds per square inch absolute (psia);
- Fixed roof tanks with capacities ≥ 25 Mgal and TVP < 11.0 psia;
- Fixed roof tanks with TVP ≥ 11.0 psia; and
- Floating roof tanks with TVP < 11.0 psia.

Requirements of these Tier I BACT determinations were considered as part of this report.

8. Other States

In developing this report, the Department attempted to survey all other state environmental agencies across the country. A total of 34 state and local agencies responded to our request for information and provided insight on their requirements for controlling emissions from petroleum storage facilities.

B. Available Control Strategies for VOC

Petroleum storage facilities generally consist of a system for receiving product, storage tanks for storing product, and a system for distributing product. These facilities also include miscellaneous equipment and processes which release air emissions, including maintenance activities. There is potential to release VOC at each point in the system.

[18] https://www.tceq.texas.gov/assets/public/permitting/air/Guidance/NewSourceReview/bact/bact-chemical.xlsx

Following is a description of the available options and strategies for control of VOC emissions from petroleum storage facilities.

1. Receiving Product

   When product is delivered to the petroleum storage facility via ship, rail, or tank truck, fresh air is drawn into the delivery vessel as product is transferred to the petroleum storage tank. Emissions from the delivery vessel are typically minimal since the product is being pumped out of the vessel and air is pulled into the vessel to replace the missing volume. However, once the product transfer is complete, there is the potential for the delivery vessel to off-gas any product remaining in its hold if it remains open to the atmosphere. Of the resources consulted, none specifically addressed sealing the delivery vessel once transfer is complete. However, this is a common practice for safety reasons as leaving the emptied delivery vessel open to the air could create a potentially explosive environment inside the delivery vessel.

   VOC may be released when product is added to a petroleum storage tank, displacing vapors from within the tank that may be saturated with product. Emissions from petroleum storage tanks, including during filling operations, are addressed in the next section.

2. Product Storage

   There are various emission control options available for petroleum storage tanks including those add-on controls for existing tanks and inherently low-emitting storage tank designs.

   Five basic types of tanks are used to store petroleum liquids: fixed roof, external floating roof, internal floating roof, domed external floating roof, and variable vapor space.

   a. Fixed Roof Tanks

      (1) Description

         A fixed roof tank is the most basic type of petroleum storage tank. Fixed roof tanks are used to store products with lower vapor pressures, such as distillate fuels, residual fuels, and asphalt.

         A typical vertical 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 be conical, domed, or flat. The tank may be heated or unheated. Heated tanks are usually insulated whereas unheated tanks often are not.

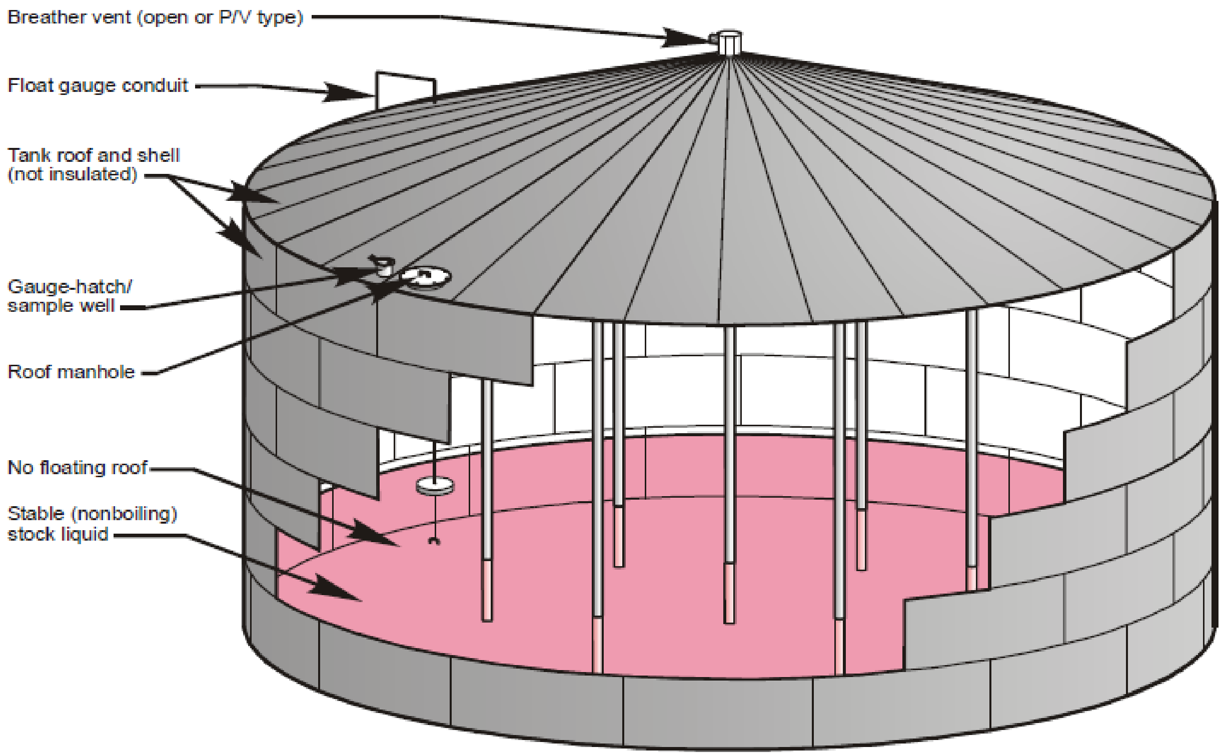

Figure 1: Typical fixed roof tank.[19]

(2) Emissions

Emissions from fixed roof tanks are caused by changes in temperature, pressure, and liquid level. When the tank is filled, the VOC-laden air above the liquid is forced out of the tank as the space is taken up by the liquid product. Emissions from actively filling the tank are known as “working losses,” and occur relatively infrequently. However, working losses may result in a large volume of VOC-laden air being exhausted from the tank over a relatively short period of time.

Fixed roof tanks can also have emissions when no product is being added or removed. These emissions, known as “breathing losses,” occur when there is an increase in temperature inside the tank. Both the liquid product and gases in the vapor space expand, forcing VOC-laden air out of the tank. When the interior of the tank cools, the opposite occurs, and fresh air is drawn into the tank as the product and gases inside the tank contract. Breathing losses result in a much smaller flow rate of vapor from the tank, but the emissions occur more frequently (daily).

[19] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

Unheated fixed roof tanks experience breathing losses as the tanks are naturally heated by the sun during the day and then cool at night. To help limit breathing losses, fixed roof tanks are often painted white or another light color to minimize solar heating.

Heated fixed roof tanks with uninsulated roofs experience breathing losses similar to unheated tanks because diurnal solar heating and cooling through the roof affects the gases in the vapor space inside the tank.

Fixed roof tanks that are fully insulated are less likely to have breathing losses driven by diurnal ambient temperature cycles. Instead, expansion and contraction of the product and vapors inside the tank may be driven by cyclic heating of the tank. Tanks are heated by furnaces or boilers that heat an intermediate fluid, usually a type of thermal oil. The heated thermal oil is circulated through pipes that heat the product being stored. If this heating process is intermittent, i.e., the product is heated to 350° F and then allowed to cool to 300° F before being heated again, then the heating and cooling cycles will cause the product and vapor inside the tank to expand and contract, causing breathing losses. However, if the product in a fully insulated tank is maintained at a constant temperature, the product and vapor in the tank stay at a constant volume, and breathing losses are essentially eliminated.

(3) Potential Control Strategies

Following are potential control strategies for fixed roof petroleum storage tanks:

(i) Low Vapor Pressure Products

Low vapor pressure products result in a vapor space within the tank that contains a lower concentration of VOC than results from higher vapor pressure products. Therefore, working and breathing losses are less when the product stored has a lower vapor pressure. Fixed roof tanks are typically only appropriate for products with vapor pressures less than 0.50 psia at 60° F such as distillate fuel, residual fuel, or asphalt.

(ii) Annual Throughput Limits

Limiting a tank’s annual throughput can limit working losses. However, it has no effect on breathing losses.

(iii) Paint Color

Many entries in the RBLC required the tank to be painted white or another reflective color. Uninsulated, fixed roof tanks experience breathing losses as the tanks are naturally heated by the sun during the day and cool at night. Painting the tank a light color minimizes solar heating.

(iv) Submerged Fill

Submerged fill describes the filling of a storage tank in a way that causes product to enter the vessel below the liquid level. For example, use of a drop tube allows the product to flow through the tube and emerge at a point near the bottom of the tank. When the tank is filled, the product level quickly rises above this point. As a consequence, most of the product entering the tank does not splash and instead flows beneath the liquid surface. Using submerged fill greatly reduces turbulence and therefore reduces vapor generation.

(v) Insulation

Breathing losses from fixed roof tanks can be nearly eliminated by keeping the vapor space inside the tank at a constant temperature. Breathing losses occur as the vapor inside the tank expands when heated. This can be due to natural heating from changes in ambient temperature and solar radiation, or tank heaters can be used to increase the product temperature.

If the tank is fully insulated, including the roof, breathing losses due to natural heating cycles are minimized. Similarly, heated tanks that are fully insulated and held at a constant temperature also have minimal emissions due to breathing losses.

(vi) Vapor Recovery Units

Vapor recovery units (VRUs) route VOC-laden vapors to a device which separates the VOC from the exhaust stream. Depending on the design, the VRU may either trap/bind the VOC to a solid to be disposed of or recover the VOC back as a liquid that can either be disposed of or piped back to the petroleum storage tank. VRUs can achieve control efficiencies for VOC greater than 98%. VRUs recover the product in the displaced vapors through adsorption or condensation.

1. Carbon Adsorption

   Carbon adsorption is the process of passing the VOC-laden air stream through a bed of adsorbent material, typically activated carbon, although other media may be suitable for certain applications. Hydrocarbons attach to the surfaces of the activated carbon particles. Carbon adsorbers are also referred to as "carbon beds."

   Carbon adsorbers can be either regenerative or non-regenerative. With non-regenerative carbon adsorption, the adsorbent eventually becomes saturated with adsorbed VOC and loses its effectiveness. The adsorbent needs to be periodically replaced and the spent material disposed of. Due to the cost to replace the spent media and the creation of an additional waste stream, non-regenerative carbon adsorption is best suited to low volume and/or low concentration streams.

   With regenerative carbon adsorption, hydrocarbons are desorbed and collected, typically by drawing a vacuum on the sorbent bed or by using heated air, steam, or nitrogen. The recovered hydrocarbons can be returned to the petroleum storage tank. A drawback of this control approach is that the adsorbent typically binds strongly to heavy hydrocarbons and is less effective at capturing lighter organics such as propane. Therefore, it may be difficult to desorb some materials, which can foul the adsorbent over time. Additionally, lighter materials are even more likely to pass through without being adequately collected if heavy hydrocarbons have already bound to the adsorbent. Therefore, regenerative carbon adsorption is typically used for VRUs associated with exhaust streams carrying gasoline or distillate fuel vapors and not used with heavier hydrocarbon products such as crude oil, residual fuels, and asphalt.

   Carbon adsorbers may be designed to reduce VOC and/or odors. However, they require an active system where fans or blowers draw a flow across the tank vents to capture emissions. If the carbon bed is not carefully monitored and maintained, the carbon media may become spent or fouled such that it no longer removes pollutants from the exhaust stream. This could have the unintended consequence of increasing emissions since the blower system will pull more vapors out of the tank than if the tank were left uncontrolled.

2. Condensers

VOC can be removed from an exhaust stream by condensing the product to a liquid. Condensation occurs when an exhaust stream that is saturated with product vapors undergoes a phase change from gas to liquid. The phase change can be achieved in two ways: The system pressure can be increased at a given temperature (i.e., compression), or the temperature may be lowered at a constant pressure (i.e., refrigeration).

For a more volatile product (i.e., a product with a low boiling point and high vapor pressure), larger amounts can remain in the vapor phase at a given temperature. To induce condensation, the exhaust stream must be cooled, compressed, or both. Therefore, it is more energy-intensive to operate a condenser to control a more volatile product (e.g., gasoline) than a less volatile product (e.g. distillate fuels). However, the less volatile products also often contain heavy, sticky compounds that can stick to the inside of a condenser, reducing its efficiency and effectiveness over time.

(vii) Vapor Combustion Units

A vapor combustion unit (VCU) raises the temperature of the exhaust stream to oxidize (burn) the VOC components. VCUs can be designed to achieve control efficiencies for VOC greater than 98%. Types of VCUs include open flares, enclosed thermal oxidizers, and regenerative thermal oxidizers.

1. Flares

Flaring is a type of thermal oxidizer that directs the VOC-laden exhaust stream through a vertical pipe to a burner assembly located well above ground level. VOC are burned in the open air using a specially designed burner tip, auxiliary fuel, and steam or air to promote mixing. Completeness of combustion in a flare is governed by flame temperature, residence time in the combustion zone, turbulent mixing of the components to complete the oxidation reaction, and available oxygen for free radical formation. Combustion is complete if all VOC are converted to carbon dioxide and water. Incomplete combustion results in some of the VOC being unaltered or converted to other organic compounds such as aldehydes or acids.

The flaring process can produce some undesirable byproducts including noise, smoke, heat radiation, light, sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and an additional source of ignition introducing additional fire hazard at a petroleum facility.

A major drawback to using an open flare is the inability to conduct performance testing. Due to its open nature, it is impossible to measure actual emissions of VOC after the control device, i.e., after the flame. Therefore, facilities which utilize a VCU for control of VOC emissions typically use an enclosed thermal oxidizer instead of an open flare where a precise measurement of actual emissions is required.

2. <u>Enclosed Thermal Oxidizers</u>

Enclosed thermal oxidizers (enclosed TOs), also known as ground flares, have burner heads which are inside an insulated shell. This equipment is located at ground level. The shell reduces noise, light, and heat radiation, and provides wind protection.

Enclosed TOs have a defined exhaust point which can be tested for control efficiency and compliance with emission limit regulations.

Enclosed TOs are most often used with exhaust streams with high concentrations of VOC, such as emissions from loading of gasoline. They are less cost-effective when used to control exhaust streams with lower concentrations of VOC. A recent analysis performed for a Maine facility indicated the cost of using a thermal oxidizing system for control of distillate vapors was approximately $600,000 per ton of pollutant controlled.

3. <u>Regenerative Thermal Oxidizers</u>

Regenerative thermal oxidizers (RTOs) preheat the inlet emissions stream with heat recovered from the exhaust gases generated by their operation. The inlet gas stream is passed through preheated ceramic media, and an auxiliary gas burner is used to heat it to between 1,450 ºF and 1,600º F at a specific residence time. The combusted gas exhaust then passes through a cooled ceramic bed where heat is extracted.

RTOs can very efficiently meet high destruction efficiencies of exhaust streams with a continuous, consistent VOC loading. However, the amount of exhaust experienced from fixed roof tanks varies widely between those experienced during daily breathing losses and intermittent working losses. Additionally, short-term batch processes, such as working losses from a fixed roof tank, are not well suited for control by an RTO. The intermittent nature of emissions in the exhaust stream means there could be significant periods of time between high VOC loads, allowing the ceramic media to cool and fail to effectively or efficiently pre-heat the incoming gases. This would result in less efficient operation and the use of more auxiliary fuel.

(viii) Mist Eliminators

Mist eliminators, also known as “demisters” or “entrainment separators,” are designed to remove mist droplets from an air stream. Unlike condensers (described below in the section on Product Distribution), mist eliminators do not involve a phase change. The product entrained in the air stream is already in a liquid form, but the droplets are small enough to become airborne.

Mist eliminators are relatively simple devices that involve passing the exhaust stream past or through some type of filter system such as wire mesh, filters, or baffles. The filter system removes liquid droplets from the air stream by three methods: initial impaction (forcing gases around a tight bend), direct interception (impacting the filter surface), and Brownian diffusion (causing chaotic and irregular movement of the particle such that it impacts other particles).

Mist eliminators have almost no control efficiency for more volatile products (e.g., gasoline) as they do not reduce emissions of product already in the gaseous phase. They do reduce emissions of aerosols or droplets of less volatile products (e.g., asphalt) at temperatures below the product’s boiling point. However, since the product is already in the liquid phase, this is considered a control method for fine particulate matter and not for VOC.

(4) Summary of Control Strategies in Use

Maine DEP regulation *Petroleum Liquid Storage Vapor Control*, 06-096 C.M.R. ch. 111, applies to fixed roof petroleum storage tanks larger than 39,000 gallons. Such tanks storing a petroleum product with a vapor pressure greater than 1.0 psia but less than 1.52 psia are required to maintain records of the average monthly storage temperatures, the type of petroleum product stored, and the maximum true vapor pressure of the product stored. Further requirements of this regulation are described in the section on floating roof tanks.

Throughout all of the resources consulted, the use of low vapor pressure products, throughput limits, white/light tank color, and submerged fill were common strategies for minimization of emissions of VOC from fixed roof petroleum storage tanks. The use of insulation was not called out specifically as a required control strategy, except that insulated portions of tanks were often exempted from the requirement to be painted a white/light color.

Tanks which store petroleum products with a true vapor pressure greater than 0.50 psia at 60 °F (e.g., gasoline) are commonly required to use some type of floating roof as a control strategy, although the Texas CEQ's Tier I BACT does provide for fixed roof tanks to be used with these higher vapor pressure products provided the tank is vented to a control device. The specific type of control device is not specified but is likely some form of VRU or VCU.

The South Coast AQMD BACT database had one entry for fixed roof tanks. This determination applied to products with a vapor pressure greater than 0.10 psia at 70 °F but less than the vapor pressure of hexane (1.9 psia) or methanol (1.5 psia) depending upon the tank. The facility was required to install a thermal oxidizer (VCU) with an assumed overall control efficiency of 95%.

Regarding products with a true vapor pressure less than 0.10 psia (e.g., distillate fuels, residual fuels, asphalt), there were no examples requiring floating roofs or add-on controls found in the Texas CEQ's Tier I BACT or the South Coast AQMD BACT database.

In their response to our survey, the State of Illinois stated that asphalt vent packages consisting of a pre-filter and mist eliminator have been permitted for control of asphalt storage tanks. While the installation of these controls for asphalt tanks is not required by state or federal rule, they are nevertheless expected to reduce emissions and potential odors.

The State of Ohio indicated that they have required the use of a carbon bed or thermal oxidizer to control emissions from some fixed roof asphalt tanks.

The State of New York is considering for a future regulatory proposal a passive vent control system such as a tank vent condenser or activated carbon filter as a requirement during the filling of asphalt tanks.

There was one entry in the RBLC where an RTO (i.e., VCU) was installed to control emissions from heated residual fuel storage tanks. This entry is from 2008 for a petroleum storage facility located in Chelsea, Massachusetts. The control system was designed to capture 95% of the vapor-laden air from the tank vent system and route it to an RTO with a 99% destruction efficiency for an overall control effectiveness of 94%. This control system was installed voluntarily by the facility owner as a strategy intended to limit emissions at the facility to minor source levels.

b. Floating Roof Tanks

(1) Description

There are three types of floating roof tanks; external floating roof tanks (EFRT), internal floating roof tanks (IFRT), and domed external floating roof tanks (domed EFRT).

(i) External Floating Roof Tanks

A typical EFRT consists of an open-top cylindrical steel shell equipped with a roof that floats on the surface of the stored liquid. The floating roof consists of a deck, deck fittings, and a rim seal system. Floating decks are constructed of welded steel plates with built-in buoyancy, allowing them to sit/float on top of the liquid. They are most commonly of two general types: pontoon or double-deck. A pontoon-type EFRT is shown in Figure 2.

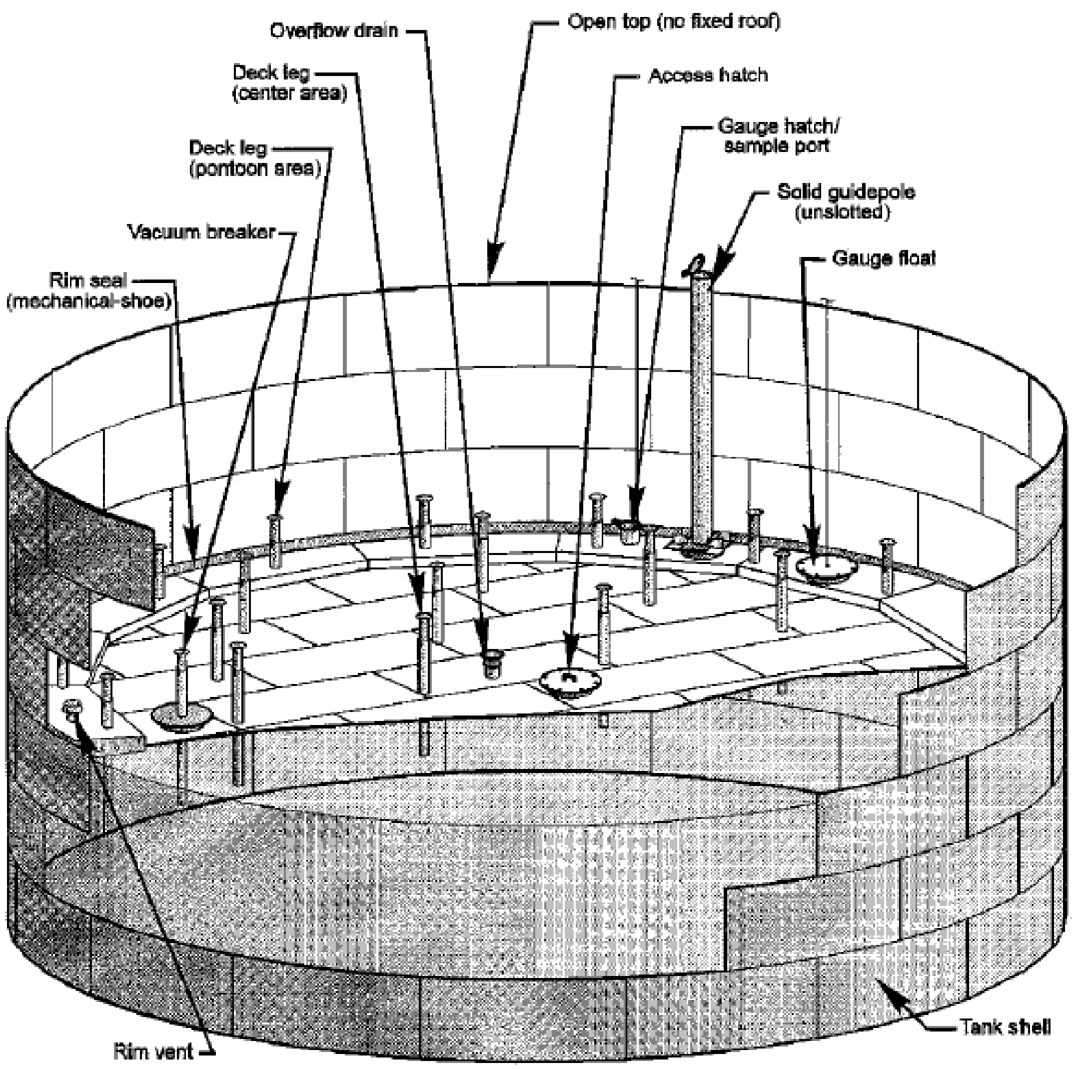

Figure 2: External floating roof tank (pontoon type)[20]

(ii) Internal Floating Roof Tanks

IFRTs have a permanent fixed roof with a floating roof inside. A typical IFRT is shown in Figure 3.

An IFRT can be designed and installed as an IFRT or can be initially designed and installed as a fixed roof tank and later retrofitted with a floating roof. The floating roofs for IFRTs tend to be thinner and do not typically have surface drains or other design elements for snow, rain, and wind considerations since the floating roof was designed for use with a fixed roof.

[20] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

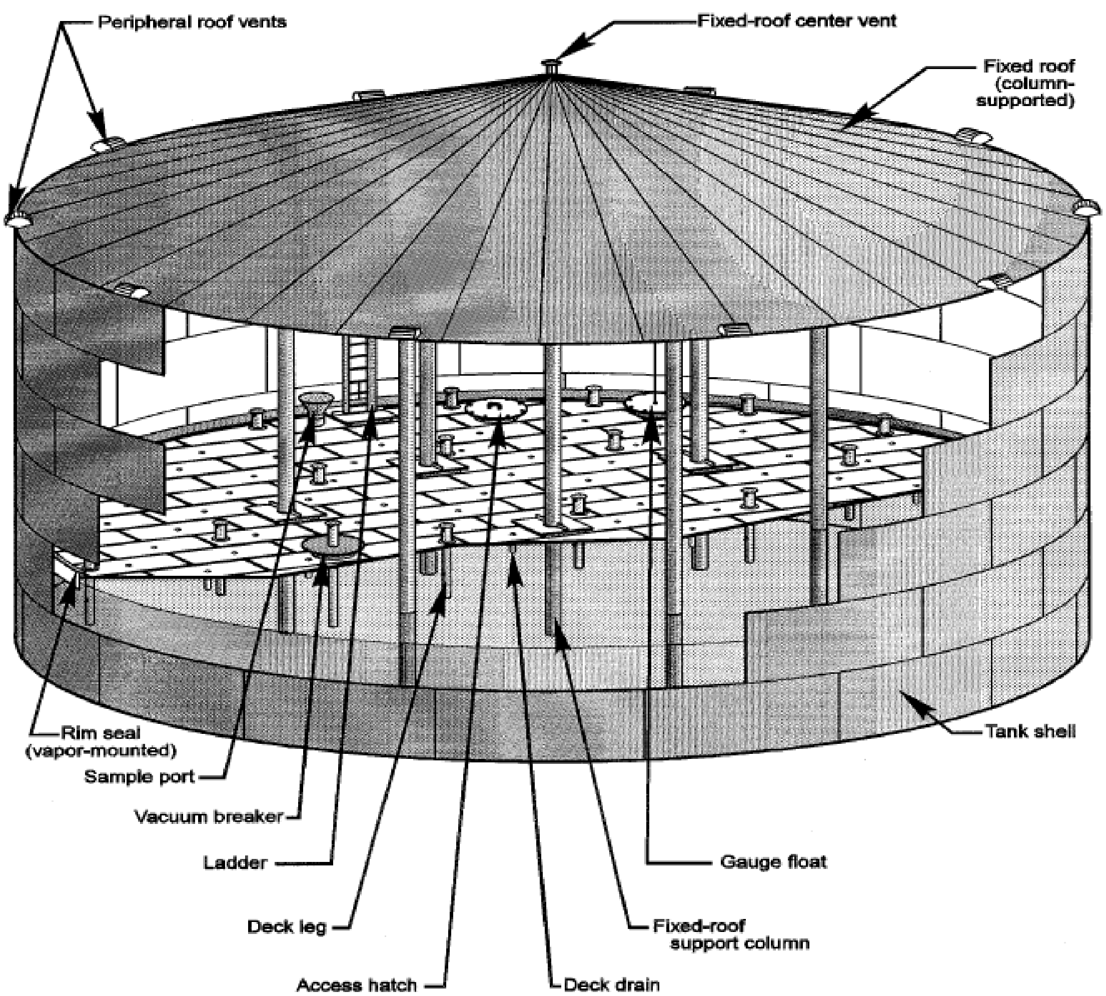

Figure 3: Internal floating roof tank[21]

There are two basic types of IFRTs: tanks in which the fixed roof is supported by vertical columns within the tank and tanks with a self-supporting fixed roof and no internal support columns. Fixed roof tanks that have been retrofitted to use a floating roof are typically of the first type. EFRTs that have been converted to IFRTs typically have a self-supporting roof. Newly constructed IFRTs may be of either type. The deck in IFRTs 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). The majority of aluminum IFRTs currently in service have noncontact decks.

Installing a floating roof minimizes evaporative losses of the stored liquid. Both contact and noncontact decks incorporate rim seals and deck fittings with purpose and function similar to those seen in EFRTs. Evaporative losses from floating roofs may come from deck fittings,

[21] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

nonwelded deck seams, and the annular space between the deck and tank wall. However, the additional fixed roof minimizes the effect of wind on evaporative losses from the floating roof.

IFRTs are usually freely vented by circulation vents at the top of the fixed roof. The vents minimize the possibility of organic vapor building up in the space between the floating roof and the fixed roof and approaching flammable and/or explosive limits.

(iii) Domed External Floating Roof Tanks

As with IFRTs, domed EFRTs have a permanent fixed roof with a floating roof inside. A typical domed EFRT is shown in Figure 4.

Domed EFRTs tend to be initially designed and installed as EFRTs with a more robust floating roof than IFRTs designed to accommodate snow, rain, and wind. The external fixed roof is usually added later to prevent water getting into the product.

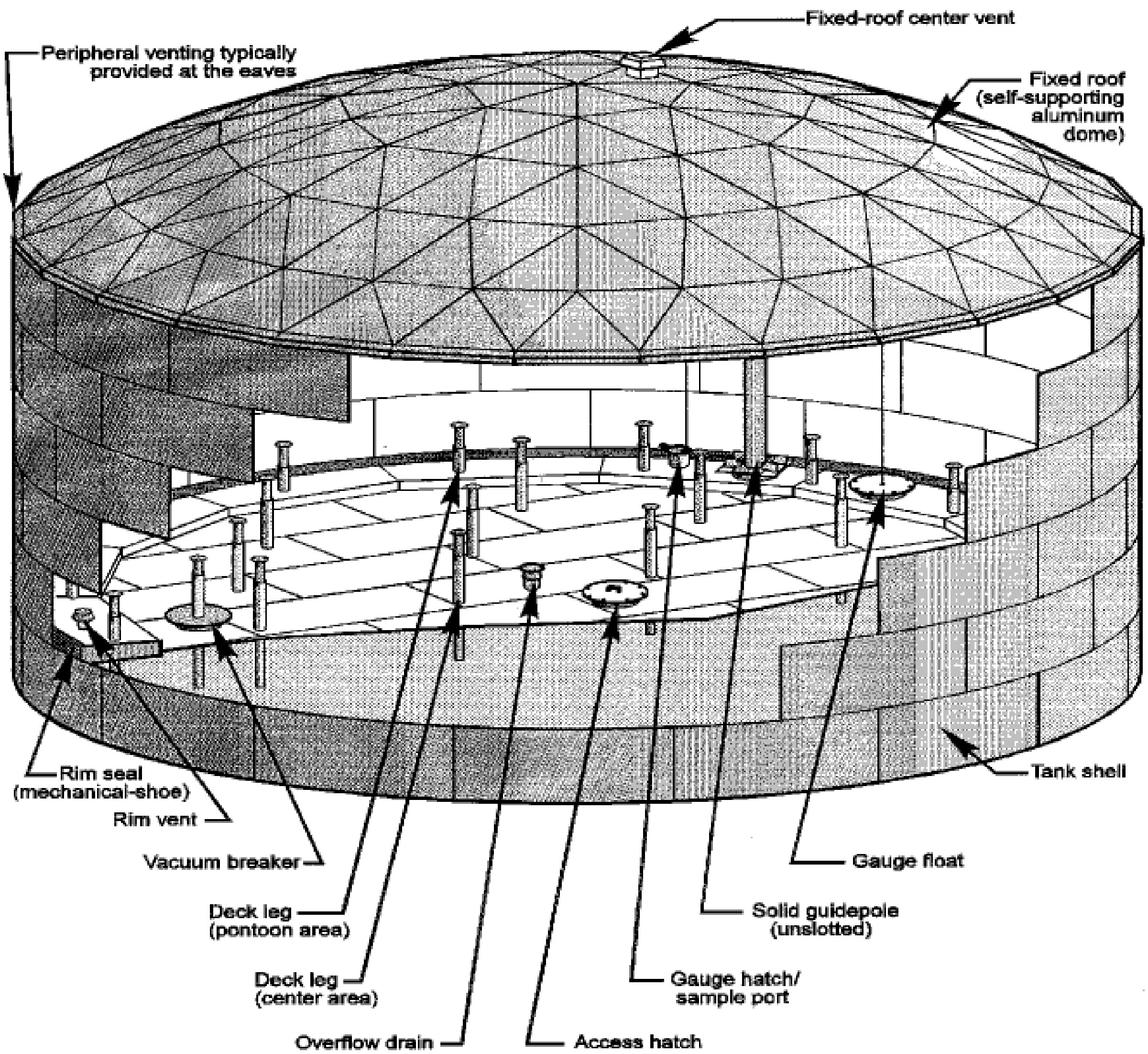

Figure 4: Domed external floating roof tank[22]

As with IFRTs, the fixed roof is not intended to act as a vapor barrier but instead to block the wind and minimize its evaporative effect.

The type of fixed roof most commonly used is a self-supporting aluminum dome roof, which is of bolted construction. Like the IFRTs, these tanks are freely vented by circulation vents at the top and around the perimeter of the fixed roof. The deck fittings and rim seals, however, are identical to those on EFRTs. In the event that the floating deck is replaced with a lighter IFRT-type deck, the tank would be reclassified as an IFRT.

[22] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

The distinction between a domed EFRT and an IFRT is primarily for purposes of recognizing differences in the deck fittings when estimating emissions. In particular, the domed EFRT deck typically has significantly taller leg sleeves than are found on an IFRT deck. The longer leg sleeves have lower associated emissions than the shorter leg sleeves of the IFRT deck. While a domed EFRT is distinct from an IFRT for purposes of estimating emissions, a domed EFRT can be considered a type of IFRT.

(2) Emissions

In all types of floating roof tanks, the roof rises and falls with the liquid level in the tank. They are equipped with a flexible rim seal system, which is attached to the deck perimeter and contacts the tank wall. The purpose of the floating roof and rim seal system is to reduce evaporative loss of the stored liquid. Some annular space remains between the seal system and the tank wall. The seal system slides against the tank wall as the roof level changes. The floating deck is also equipped with deck fittings that penetrate the deck and serve operational functions.

Unlike fixed roof tanks which have “working losses” and “breathing losses,” emissions from floating roof tanks are the sum of “working losses” and “standing losses.” Working losses (also known as withdrawal losses) from a floating roof tank occur when product is transferred out of the tank. Some product is left behind on the tank walls, and emissions occur when this product evaporates when the walls are exposed as the roof level drops. For IFRTs that have a column supported fixed roof, some product also clings to the columns and evaporates.

Standing losses from floating roof tanks include rim seal and deck fitting losses for floating roof tanks with welded decks and include deck seam losses for constructions other than welded decks.

Rim seal losses can occur through many complex mechanisms, but for EFRTs, the majority of rim seal vapor losses have been found to be wind induced. No dominant wind loss mechanism has been identified for IFRTs or domed EFRT rim seal losses. Losses can also occur due to permeation of the rim seal material by the vapor or via a wicking effect of the liquid, but permeation of the rim seal material generally does not occur if the correct seal fabric is used. Testing has indicated that breathing, solubility, and wicking loss mechanisms are small in comparison to the wind-induced loss.

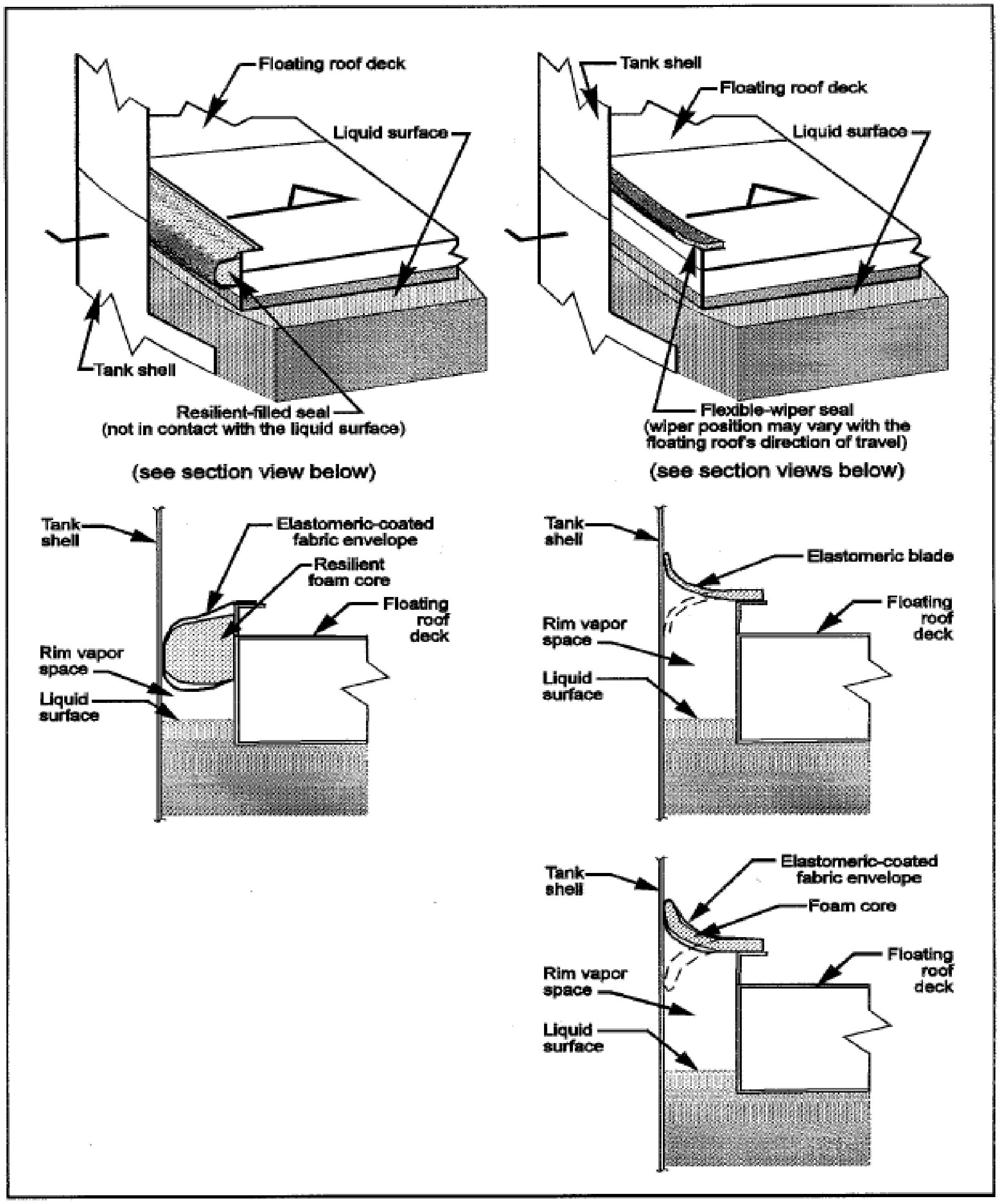

Figure 5: Vapor-mounted primary seals[23]

The rim seal system is used to allow the floating roof to rise and fall within the tank as the liquid level changes. The rim seal system also helps to fill the annular space between the rim and the tank shell and therefore minimize evaporative losses from this area. A rim seal system may consist of just a primary seal or a primary and a secondary seal, which is mounted above the

[23] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

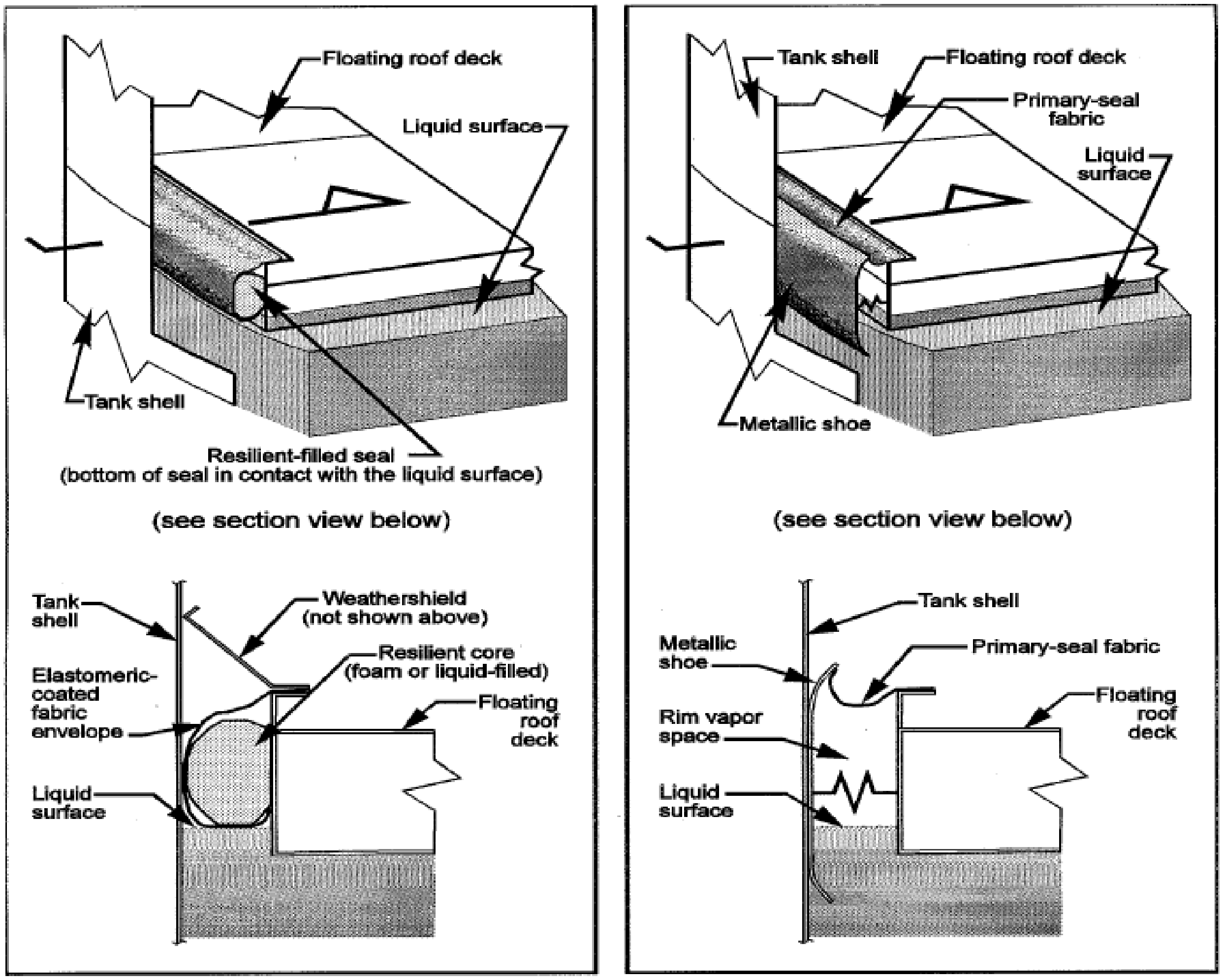

Figure 6: Liquid-mounted and mechanical shoe primary seals[24]

primary seal. Examples of primary and secondary seal configurations are shown in Figure 5, Figure 6, and Figure 7.

[24] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

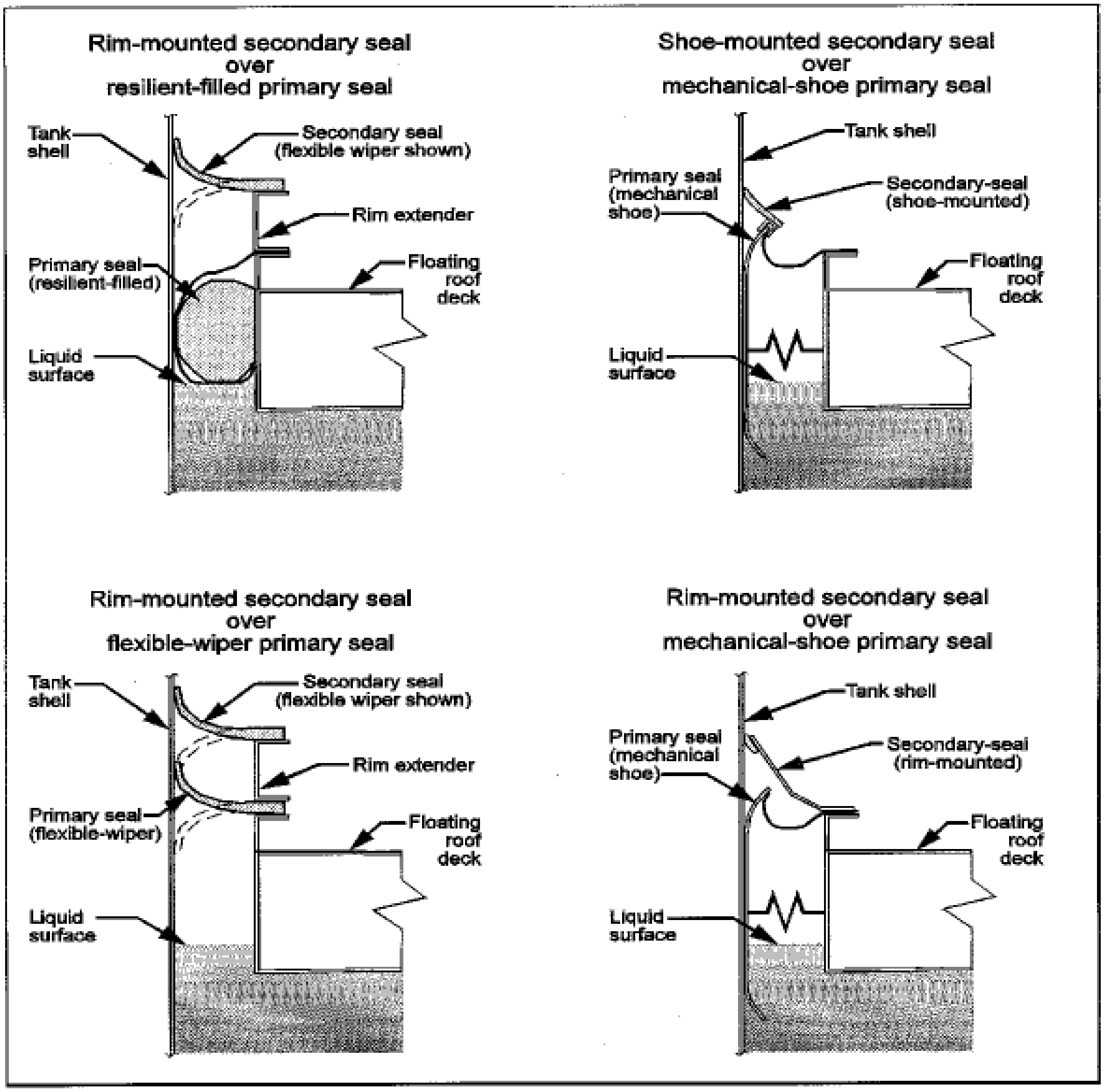

Figure 7: Secondary rim seals[25]

The primary seal serves as a vapor conservation device by closing the annular space between the edge of the floating deck and the tank wall. Three basic types of primary seals are used on floating roofs: mechanical (metallic) shoe, resilient filled (nonmetallic), and flexible wiper seals. Some primary seals on external floating roof tanks are protected by a weather shield. Weather shields may be of metallic, elastomeric, or composite materials and provide the primary seal with longer life by protecting the primary seal fabric from deterioration due to exposure to weather, debris, and sunlight. Mechanical shoe seals, resilient filled seals, and wiper seals are discussed below.

[25] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

A mechanical shoe seal uses a light-gauge metallic band as the sliding contact with the shell of the tank, as shown in Figure 6. The band is formed as a series of sheets (shoes) which are joined together to form a ring and are held against the tank shell by a mechanical device. The shoes are normally 3 to 5 feet deep when used on an EFRT and are often shorter when used on an IFRT.

Expansion and contraction of the ring can be provided for as the ring passes over shell irregularities or rivets by jointing narrow pieces of fabric into the ring or by crimping the shoes at intervals. The bottoms of the shoes extend below the liquid surface to confine the rim vapor space between the shoe and the floating deck.

The rim vapor space, which is bounded by the shoe, the rim of the floating deck, and the liquid surface, is sealed from the atmosphere by bolting or clamping a coated fabric to the shoe. This “primary seal fabric” extends from the shoe to the rim to form an "envelope". Two locations are used for attaching the primary seal fabric; most commonly the top of the shoe and the rim of the floating deck. To reduce the rim vapor space, the fabric can be attached to the shoe and the floating deck rim near the liquid surface. Rim vents can be used to relieve any excess pressure or vacuum in the vapor space.

A resilient filled seal can be configured to allow a vapor space between the rim seal and the liquid surface (vapor mounted), or to eliminate the vapor space between the rim seal and liquid surface (liquid mounted). These configurations are shown in Figure 5 and Figure 6 respectively. Resilient filled seals work as the expansion and contraction of a resilient material maintains contact with the tank shell while accommodating variations in the width of the annular rim space. These rim seals allow the roof to move up and down freely, without binding.

Resilient filled seals typically consist of a core of open-cell foam encapsulated in a coated fabric. The seals are mounted on the deck perimeter and extend around the deck circumference. Polyurethane-coated nylon fabric and polyurethane foam are commonly used materials. For emission control, it is important that the attachment of the seal to the deck and the radial seal joints be vapor-tight and that the seal be in substantial contact with the tank shell.

Wiper seals generally consist of a continuous annular blade of flexible material fastened to a mounting bracket on the deck perimeter that spans the annular rim space and contacts the tank shell. This type of seal is depicted in Figure 5. New tanks with wiper seals may have dual wipers, one mounted above the other. The mounting is such that the blade is flexed, and its elasticity provides a sealing pressure against the tank shell.

Wiper seals are vapor mounted; a vapor space exists between the liquid stock and the bottom of the seal. For emission control, it is important that the mounting be vapor-tight, that the seal extend around the circumference of the deck, and that the blade be in substantial contact with the tank shell. Two types of materials are commonly used to make the wipers. One type consists of a cellular, elastomeric material tapered in cross section with the thicker portion at the mounting. Rubber is a commonly used material; urethane and cellular plastic are also available. All radial joints in the blade are joined. The second type of material that can be used is a foam core wrapped with a coated fabric. Polyurethane on nylon fabric and polyurethane foam are common materials. The core provides the flexibility and support, while the fabric provides the vapor barrier and wear surface.

A secondary seal may be used to further reduce evaporative loss beyond that achieved by the primary seal. Secondary seals can be either flexible wiper seals or resilient filled seals. For mechanical shoe primary seals, two configurations of secondary seals are available: shoe mounted and rim mounted, as shown in Figure 7. Rim mounted secondary seals are more effective in reducing losses than shoe mounted secondary seals because they cover the entire rim vapor space. For IFRTs, the secondary seal is mounted to an extended vertical rim plate, above the primary seal, as shown in Figure 7. However, for some floating roof tanks, using a secondary seal further limits the tank's operating capacity due to the need to keep the seal from interfering with fixed roof rafters or to keep the secondary seal in contact with the tank shell when the tank is filled.

The deck fitting losses from floating roof tanks can be explained by the same mechanisms as the rim seal losses. While the relative contribution of each mechanism to the total emissions from a given deck fitting is not known, emission factors have been developed for individual deck fittings by testing, thereby accounting for the combined effect of all of the mechanisms.

Numerous fittings pass through or are attached to floating roof decks to accommodate structural support components or allow for operational functions. Internal floating roof deck fittings are typically of different configuration than those for external floating roof decks. Rather than having tall housings to avoid rainwater entry, internal floating roof deck fittings tend to have lower profile housings to minimize the potential for the fitting to contact the fixed roof when the tank is filled. Deck fittings can be a source of evaporative loss when they require openings in the deck. The most common components that require openings in the deck are described below.

<u>Access hatches</u>

An access hatch is an opening in the deck with a peripheral vertical well that is large enough to provide passage for workers and materials through the deck for construction or servicing. Attached to the opening is a removable cover that may be bolted and/or gasketed to reduce evaporative loss. On IFRTs with noncontact decks, the well should extend down into the liquid to seal off the vapor space below the noncontact deck. A typical access hatch is shown in Figure 8.

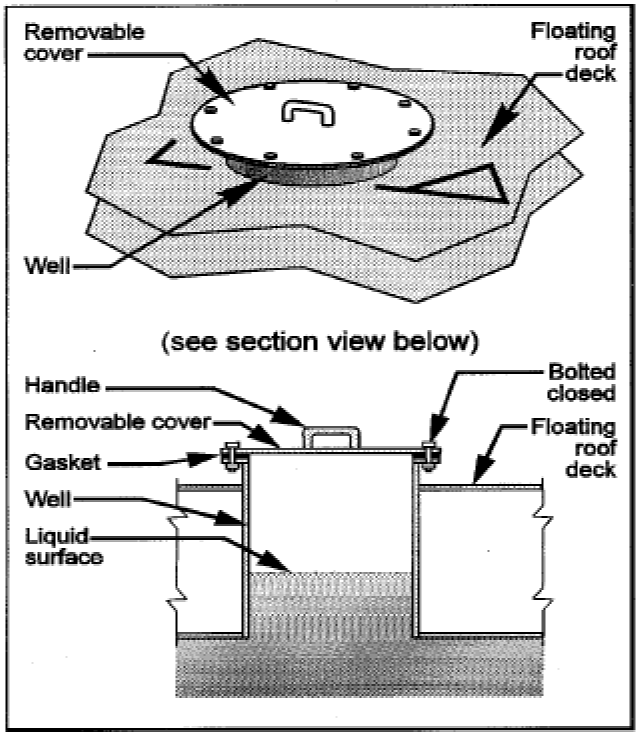

Figure 8: Access Hatch[26]

Gauge-floats

A gauge-float is used to indicate the level of liquid within the tank. The float rests on the liquid surface and is housed inside a well that is closed by a cover. The cover may be bolted and/or gasketed to reduce evaporation loss. As with other similar deck penetrations, the well extends down into the liquid on noncontact decks in internal floating roof tanks. A typical gauge-float and well are shown in Figure 9.

[26] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

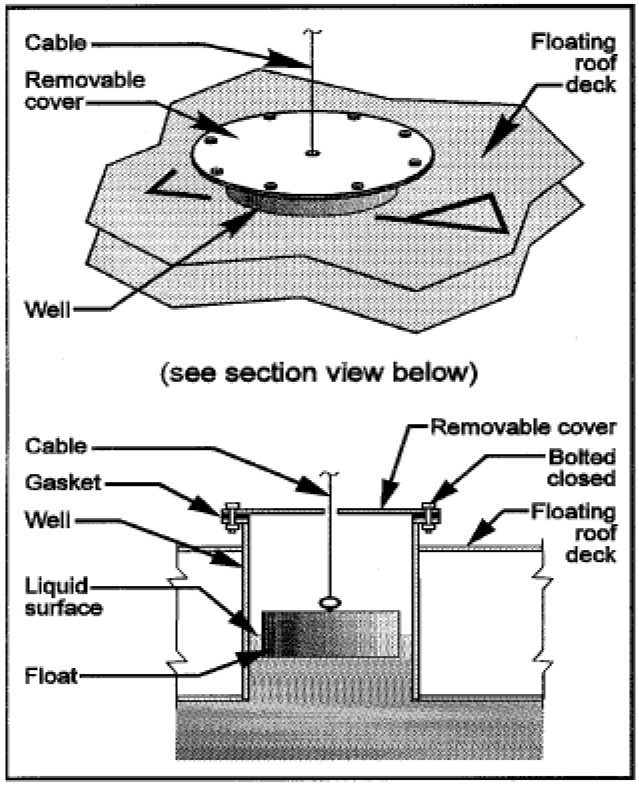

Figure 9: Gauge Float[27]

Gauge-hatch/sample ports

A gauge-hatch/sample port consists of a pipe sleeve through the deck for hand-gauging or sampling of the stored liquid. The gauge-hatch/sample port is usually located beneath a gauger's platform, which is mounted on top of the tank shell. A cover may be attached to the top of the opening, and the cover may be equipped with a gasket to reduce evaporative losses. A cord may be attached to the cover so that the cover can be opened from the platform. Alternatively, the opening may be covered with a slit-fabric seal. A funnel may be mounted above the opening to guide a sampling device or gauge stick through the opening. A typical gauge-hatch/sample port is shown in Figure 10.

[27] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

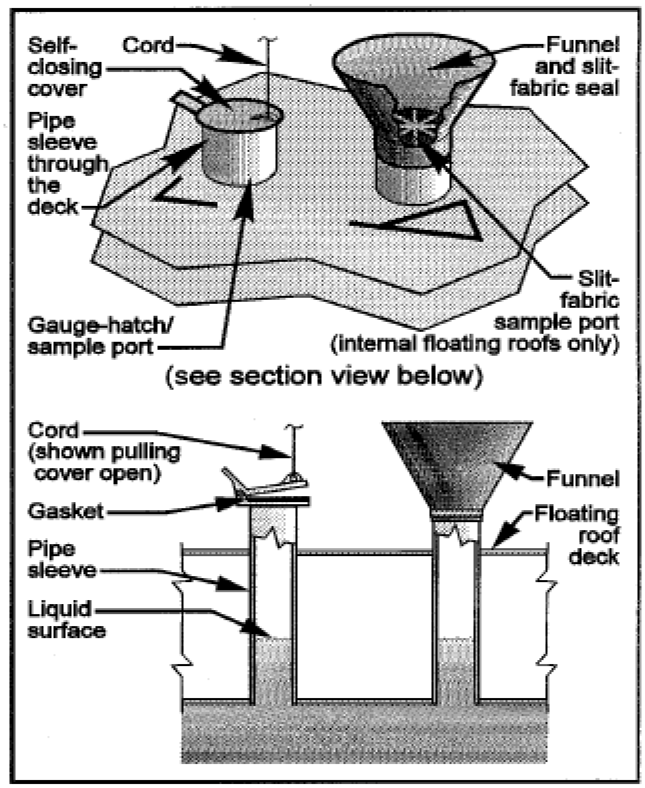

Figure 10: Gauge-hatch / Sample Port[28]

Rim vents

Rim vents are used on tanks equipped with a seal design that creates a vapor pocket in the seal and rim area, such as a mechanical shoe seal. A typical rim vent is shown in Figure 11. The vent is used to release any excess pressure that is present in the vapor space bounded by the primary-seal shoe and the floating roof rim and the primary seal fabric and the liquid level. Rim vents usually consist of weighted pallets that rest over the vent opening.

[28] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

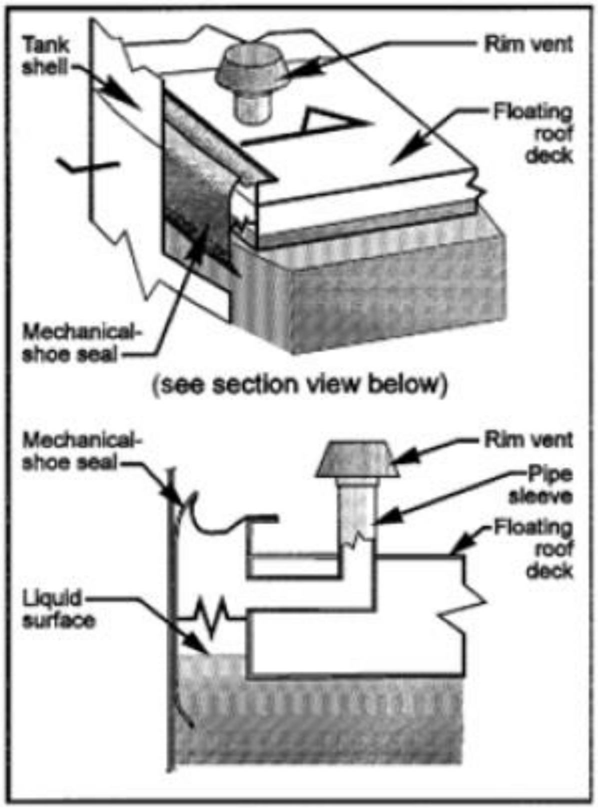

Figure 11: Rim Vent[29]

Deck drains

Currently two types of deck drains (closed and open deck drains) are in use to remove rainwater from a floating deck. Open deck drains can be either flush or overflow drains. Both types of open deck drains consist of a pipe that extends below the deck to allow the rainwater to drain into the stored liquid. Only open deck drains are subject to evaporative loss. Flush drains are flush with the deck surface. Overflow drains are elevated above the deck surface. Typical overflow and flush deck drains are shown in Figure 12. Overflow drains are used to limit the maximum amount of rainwater that can accumulate on the floating deck, providing emergency drainage of rainwater if necessary. Closed deck drains carry rainwater from the surface of the deck though a flexible hose or some other type of piping system that runs through the stored liquid prior to exiting the tank. The rainwater does not come in contact with the liquid, so no evaporative losses result. Overflow drains are usually used in conjunction with a closed drain system to carry rainwater outside the tank.

[29] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

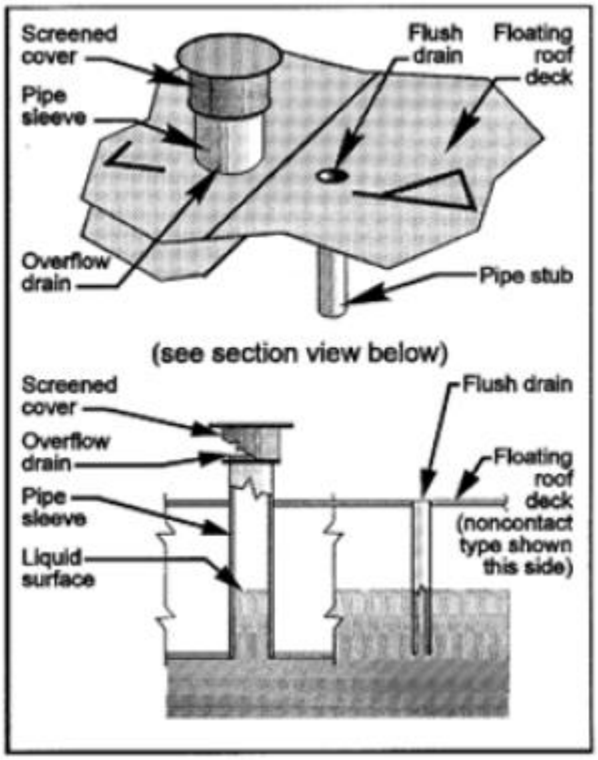

Figure 12: Deck Drains[30]

Deck legs

Deck legs are used to prevent damage to fittings underneath the deck and to allow for tank cleaning or repair, by holding the deck at a predetermined distance off the tank bottom. These supports consist of adjustable or fixed legs attached to the floating deck or hangers suspended from the fixed roof. For adjustable legs or hangers, the load-carrying element may pass through a well or sleeve into the deck. With noncontact decks, the well should extend into the liquid. Evaporative losses may occur in the annulus between the deck leg and its sleeve. A typical deck leg is shown in Figure 13.

[30] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

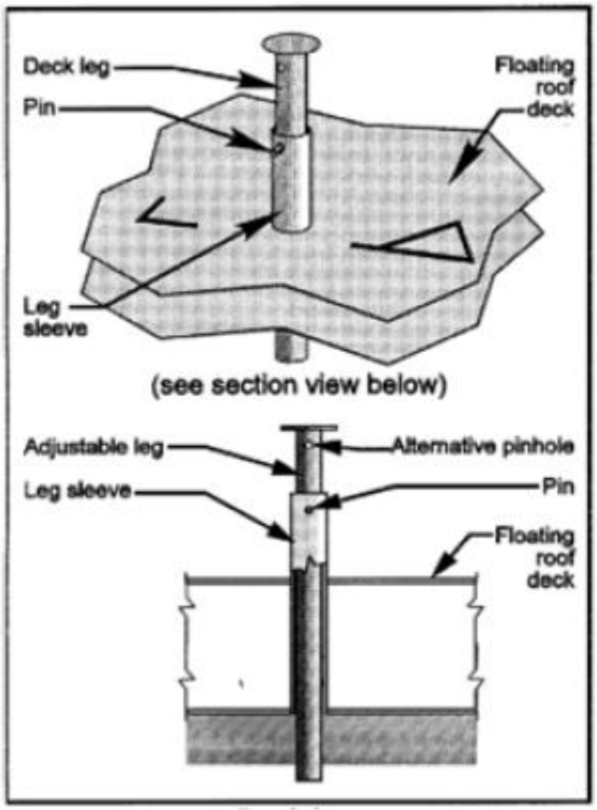

Figure 13: Deck Leg[31]

Unslotted guidepoles and wells

A guidepole is an anti-rotational device that is fixed to the top and bottom of the tank, passing through a well in the floating roof. The guidepole is used to prevent adverse movement of the roof (e.g., spinning) and thus damage to deck fittings and the rim seal system. In some cases, an unslotted guidepole is used for gauging purposes, but there is a potential for differences in the pressure, level, and composition of the liquid inside and outside of the guidepole. A typical unslotted guidepole and well are shown in Figure 14.

[31] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

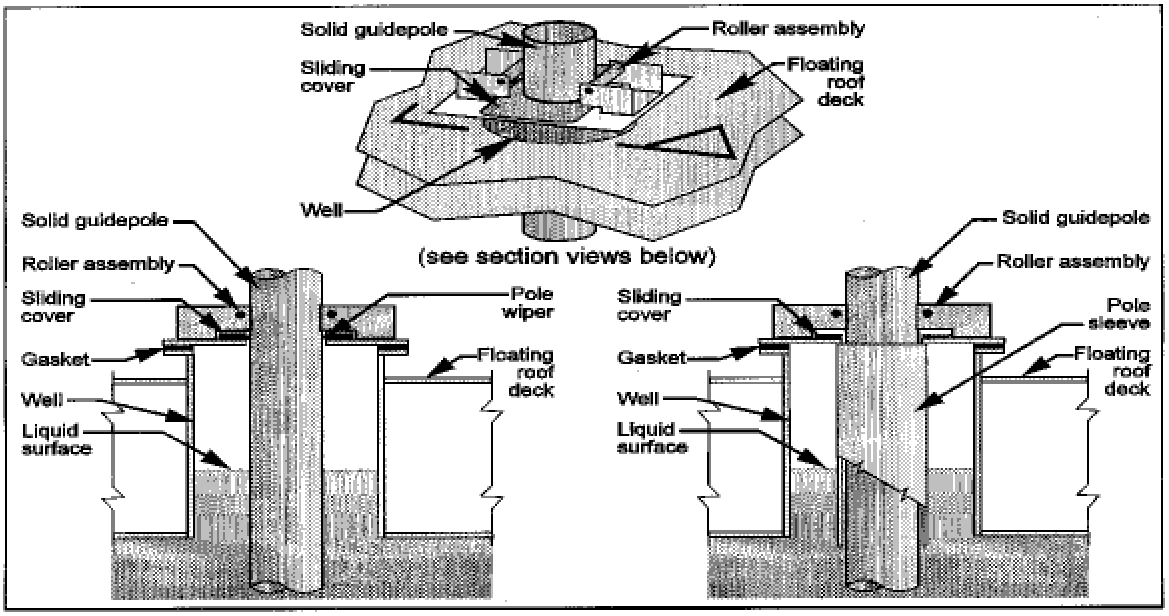

Figure 14: Unslotted (solid) Guidepole[32]

<u>Slotted (perforated) guidepoles and wells</u>

The function of the slotted guidepole is similar to the unslotted guidepole but with additional features. Perforated guidepoles can be either slotted or drilled hole guidepoles. A typical slotted guidepole and well are shown in Figure 15. As shown in this figure, the guide pole is slotted to allow stored liquid to enter. The same can be accomplished with drilled holes. The liquid entering the guidepole has the same composition as the remainder of the stored liquid and is at the same liquid level as the liquid in the tank. Representative samples can therefore be collected from the slotted or drilled hole guidepole. Evaporative loss from the guidepole can be reduced by a combination of modifying the guidepole or well with the addition of gaskets, sleeves, or enclosures or placing a float inside the guidepole, as shown in Figure 15 and Figure 16. Guidepoles are also referred to as gauge poles, gauge pipes, or stilling wells.

[32] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

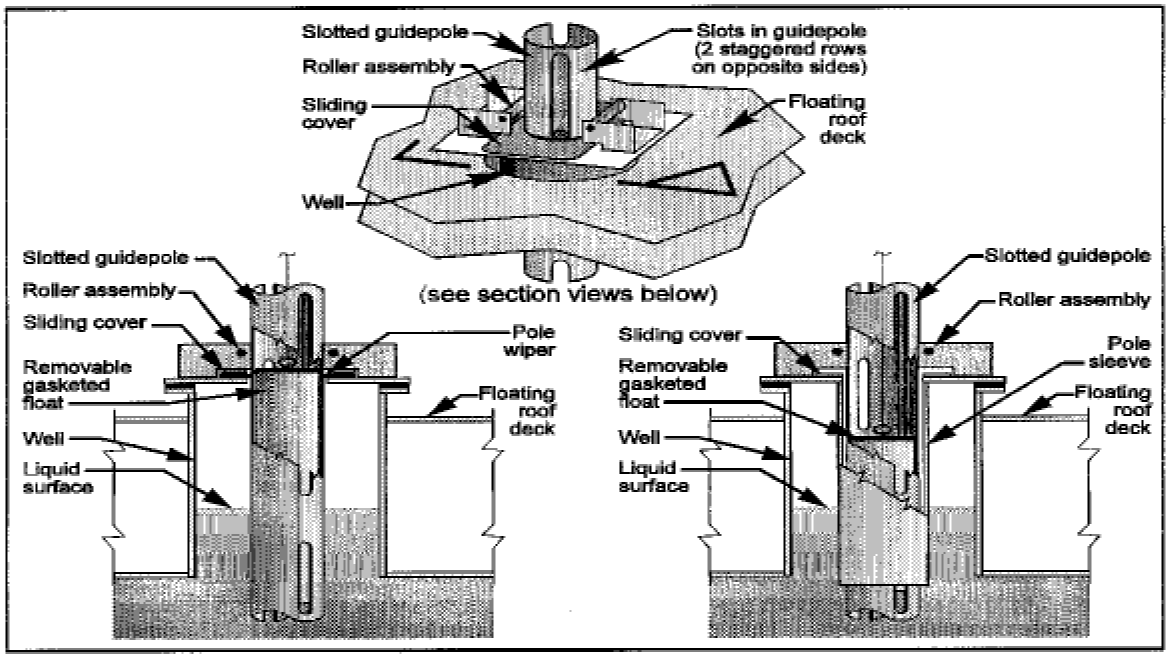

Figure 15: Slotted (perforated) Guidepole[33]

[33] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

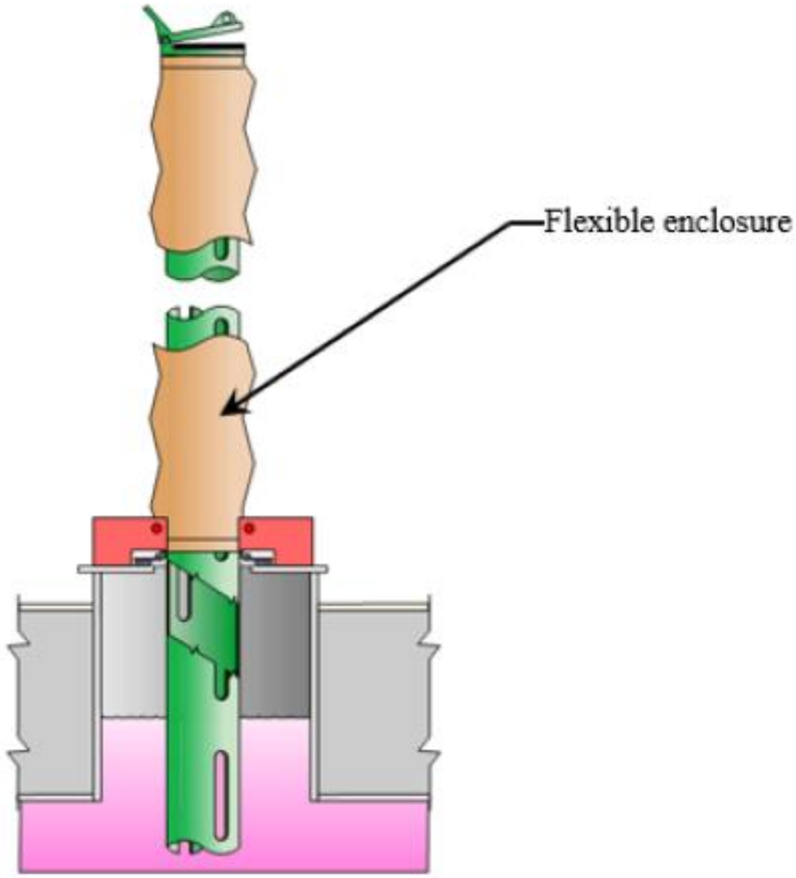

Figure 16: Slotted-guidepole with flexible enclosure[34]

Vacuum breakers

A vacuum breaker equalizes the pressure of the vapor space across the deck as the deck is either being landed on or floated off its legs. A typical vacuum breaker is shown in Figure 17. As depicted in this figure, the vacuum breaker consists of a well with a cover. Attached to the underside of the cover is a guided leg long enough to contact the tank bottom as the floating deck approaches. When in contact with the tank bottom, the guided leg mechanically opens the breaker by lifting the cover off the well; otherwise, the cover closes the well. The closure may be gasketed or ungasketed. Because the purpose of the vacuum breaker is to allow the free exchange of air and/or vapor, the well does not extend appreciably below the deck. While vacuum breakers have historically tended to be of the leg-actuated design described above, they may also be vacuum actuated similar to the pressure/vacuum vent on a fixed roof tank such that they do not begin to open until the floating roof has actually landed. In some cases, this is achieved by replacing the rim vent described above with a pressure/vacuum vent.

[34] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

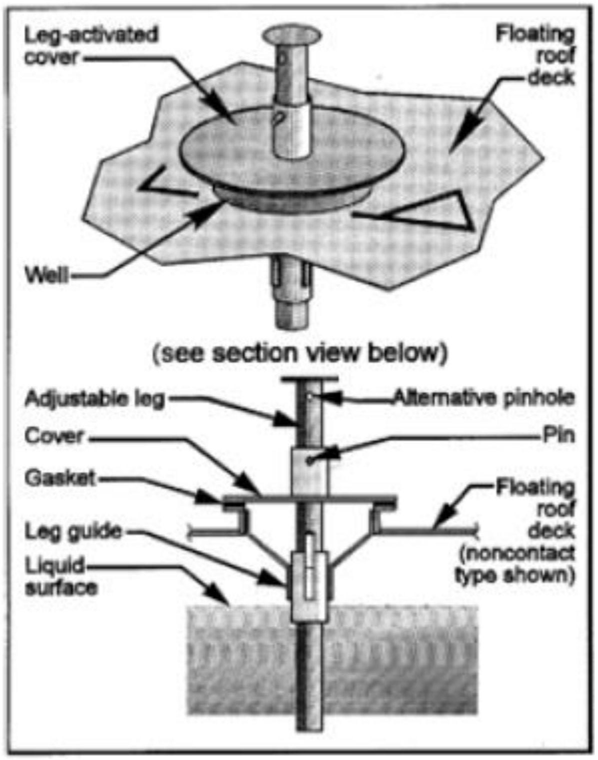

Figure 17: Vacuum Breaker[35]

The following are fittings typically used only on internal floating roof tanks:

Columns and wells

Some fixed-roof designs are normally supported from inside the tank by means of vertical columns, which necessarily penetrate an internal floating deck. (Some fixed roofs are entirely self-supporting from the perimeter of the roof, and therefore have no interior support columns.) Column wells resemble unslotted guide pole wells on external floating roofs. Columns are made of pipe with circular cross sections or of structural shapes with irregular cross sections (built-up). The number of columns varies with tank diameter, from a minimum of 1 to over 50 for very large diameter tanks. A typical fixed roof support column and well are shown in Figure 18.

[35] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

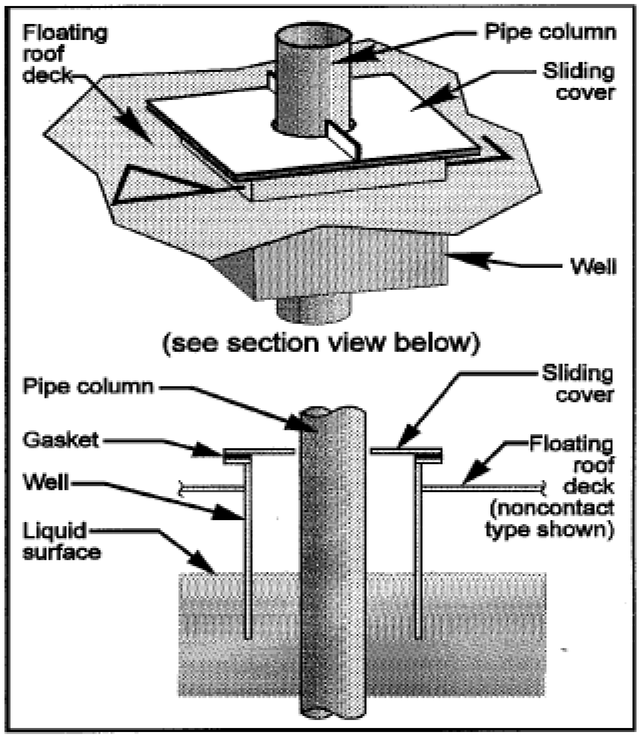

Figure 18: Fixed-Roof Support Column[36]

The columns pass through deck openings via peripheral vertical wells. With noncontact decks, the well should extend down into the liquid. Generally, a closure device exists between the top of the well and the column. Several proprietary designs exist for this closure, including sliding covers and fabric sleeves, which must accommodate the movements of the deck relative to the column as the liquid level changes. A sliding cover rests on the upper rim of the column well (which is normally fixed to the deck) and bridges the gap or space between the column well and the column. The cover, which has a cutout, or opening, around the column slides vertically relative to the column as the deck raises and lowers. At the same time, the cover may slide horizontally relative to the rim of the well to accommodate a column that is out of plumb. A gasket around the rim of the well reduces emissions from this fitting. A flexible fabric sleeve seal between the rim of the well and the column (with a cutout or opening to allow vertical motion of the seal relative to the columns) similarly accommodates any limited horizontal motion of the deck relative to the column.

<u>Ladders and wells</u>

Some tanks are equipped with internal ladders that extend from a manhole in the fixed roof to the tank bottom. The deck opening through which the ladder passes is constructed with design details and considerations similar to those

[36] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

for deck openings for column wells, as previously discussed. A typical ladder well is shown in Figure 19.

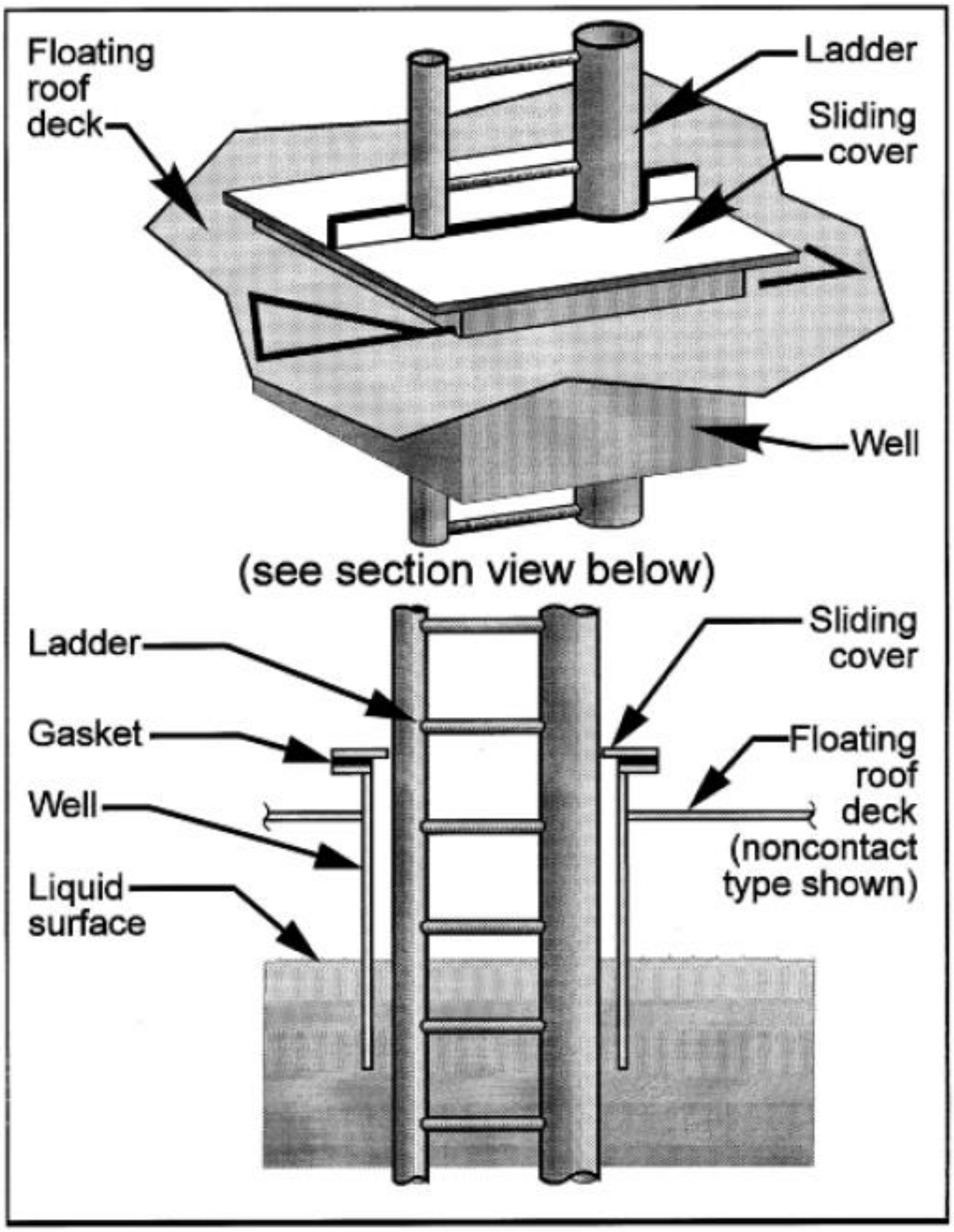

Figure 19: Ladder Well[37]

Tanks are sometimes equipped with a ladder-slotted guidepole combination, in which one or both legs of the ladder is a slotted pipe that serves as a guidepole for purposes such as level gauging and sampling. A ladder-slotted guidepole combination is shown in Figure 20 with a ladder sleeve to reduce emissions.

[37] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

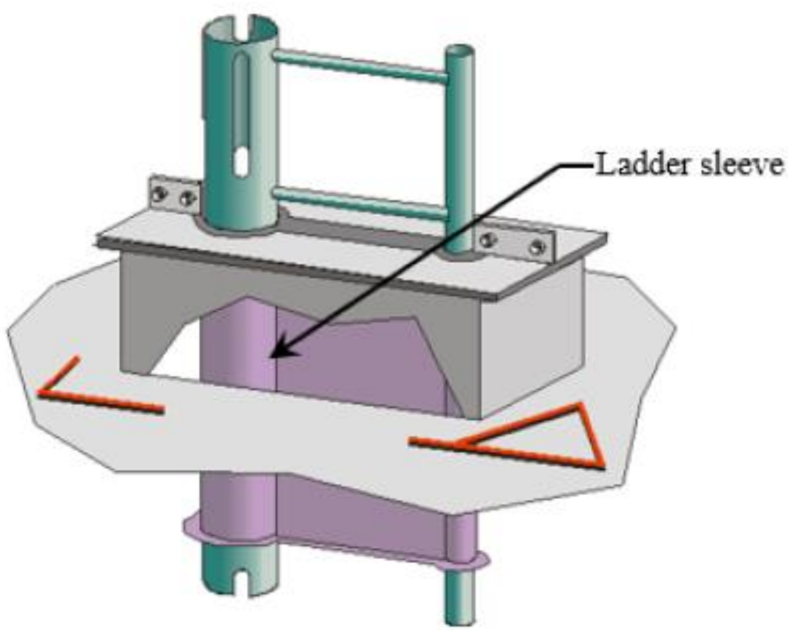

Figure 20: Ladder-slotted guidepole combination with ladder sleeve[38]

<u>Stub drains</u>

Bolted internal floating roof decks are typically equipped with stub drains to allow any product that may be on the deck surface to drain back to the underside of the deck. The drains are attached so that they are flush with the upper deck. Stub drains are approximately 1 inch in diameter and extend down into the product on noncontact decks. A typical flush stub drain is shown in Figure 12. Stub drains may be equipped with floating balls to reduce emissions. The floating ball acts as a check valve, in that it remains covering the stub drain unless liquid is present to lift it.

<u>Deck seams</u>

Deck seams in IFRTs are a source of emissions to the extent that these seams may not be completely vapor tight if they are not welded. A weld sealing a deck seam does not have to be structural (i.e., may be a seal weld) to constitute a welded deck seam for purposes of estimating emissions, but a deck seam that is bolted or otherwise mechanically fastened and sealed with elastomeric materials or chemical adhesives is not a welded seam. Generally, the same loss mechanisms for deck fittings apply to deck seams.

[38] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

(3) Potential Control Strategies

The use of a floating roof is itself a strategy to control emissions of VOC from petroleum storage tanks. The floating roof design is such that routine evaporative losses from the stored liquid are limited to the standing and working losses described above. Since the vapor space between the product surface and the tank roof is minimized, there are no breathing losses as would occur in a fixed roof tank. Although there are working losses, they are substantially different from the working losses of a fixed roof tank. Again, there is no vapor space to purge when the tank is filled. Instead, working losses occur when the tank is emptied based on the amount of product that clings to the walls as the roof descends.

Following are additional potential control considerations for floating roof petroleum storage tanks:

(i) Secondary Rim Seals

Secondary seals provide additional control of VOC losses through evaporation over that achieved by the primary seal.

(ii) Gasketed Sliding Covers

The use of gaskets or sleeves minimizes VOC losses through evaporation.

(iii) Welded Deck Seams

Welded deck seams are more vapor-tight than bolted seams.

(iv) Fixed Roofs

Both IFRTs and domed EFRTs have a permanent fixed roof with a floating roof inside. The fixed roof does not act as a vapor barrier but does work to block the wind. Emissions from rim seals and deck fittings are partly dependent on wind speed. When a tank is equipped with a fixed roof over the floating roof, the wind-dependent component is reduced to zero leaving only wind-independent losses.

(4) Summary of Control Strategies in Use

As explained above, the use of a floating roof is itself a strategy to control emissions of VOC from a petroleum storage tank.

Maine DEP's regulation *Petroleum Liquid Storage Vapor Control*, 06-096 C.M.R. ch. 111, applies to fixed roof petroleum storage tanks larger than 39,000 gallons. Such a tank storing a petroleum product with a vapor pressure greater than 1.52 psia is required to be equipped with an internal floating roof or an equally effective alternative control approved by the DEP Commissioner and the US EPA.

The following federal regulations address emissions from petroleum storage tanks.

(i) *Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced After June 11, 1973, and Prior to May 19, 1978*, 40 C.F.R. Part 60, Subpart K, applies to petroleum storage tanks with a capacity between 40,000 and 65,000 gallons that were constructed, reconstructed, or modified between March 8, 1974, and May 9, 1978 as well as to petroleum storage tanks greater than 65,000 gallons constructed, reconstructed, or modified between June 11, 1973, and May 19, 1978. Subpart K requires a tank storing a product with a vapor pressure greater than 1.5 psia (e.g., gasoline) to be equipped with a floating roof or vapor recovery system. This regulation contains no requirements for products with vapor pressures less than 1.5 psia.

(ii) *Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced After May 18, 1978, and Prior to July 23, 1984*, 40 C.F.R. Part 60, Subpart Ka, applies to petroleum storage tanks constructed, reconstructed or modified in the time period listed that have a capacity greater than 40,000 gallons. Subpart Ka requires a tank which stores a product with a vapor pressure between than 1.5 and 11.1 psia (e.g., gasoline) to be equipped with one of the following: an external floating roof with both primary and secondary seals, an internal floating roof, or a vapor collection/reduction system designed to achieve 95% reduction of emissions. If the external floating roof option is chosen, the primary seal must be a mechanical shoe seal, a liquid-mounted seal, or a vapor-mounted seal. If either floating roof option is chosen, openings in the roof must be equipped with covers, lids, or seals. This regulation contains no requirements for products with vapor pressures less than 1.5 psia.

(iii) *Standards of Performance for Volatile Organic Liquid Storage Vessels (Including Petroleum Liquid Storage Vessels) for Which Construction, Reconstruction, or Modification Commenced After July 23, 1984*, 40 C.F.R. Part 60, Subpart Kb applies to storage vessels (including petroleum storage tanks) constructed, reconstructed, or modified after July 23, 1984, which have a capacity between 20,000 and 40,000 gallons and store products with a vapor pressure greater than 0.5 psia or which have a capacity greater than 40,000 gallons and store products with a vapor pressure greater than 2.2 psia.

Subpart Kb requires storage tanks between 20,000 and 40,000 gallons which store products with vapor pressures between 3.9 and 1.1 psia and storage tanks greater than 40,000 gallons which store products with vapor pressures between 0.75 and 11.1 psia to use one of the following control strategies:

1. Use of a fixed roof with an internal floating roof. The internal floating roof must use either a mechanical shoe seal, a liquid-mounted seal, or two seals (i.e., primary and secondary seals) mounted one above the other. Openings in the roof must be equipped with covers, lids, sleeves, gaskets, or similar seals.
2. Use of an external floating roof with both primary and secondary seals. The primary seal must be a mechanical shoe seal or liquid-mounted seal. Openings in the roof must be equipped with covers, lids, or seals.
3. Use of a closed vent system and control device designed to achieve 95% reduction of emissions.

(iv) *National Emission Standards for Hazardous Air Pollutants for Source Category: Gasoline Distribution Bulk Terminals, Bulk Plants, and Pipeline Facilities*, 40 C.F.R. Part 63, Subpart BBBBBB contains requirements for petroleum storage tanks at bulk gasoline plants and bulk gasoline terminals.

Bulk gasoline plants are facilities with a maximum gasoline throughput of less than 20,000 gallons per day. (Maine has no facilities in this category.) Gasoline storage tanks at bulk gasoline plants must use submerged fill, and the facility must perform a monthly leak inspection of all equipment in gasoline service.

Bulk gasoline terminals have a maximum gasoline throughput of 20,000 gallons per day or more. (Maine has eight licensed bulk gasoline terminals.) Subpart BBBBBB requires gasoline storage tanks at bulk gasoline terminals that have a capacity of less than 20,000 gallons or a capacity of less than 40,000 gallons and a throughput of less than

480 gallons per day to be equipped with fixed roofs provided all openings are in the closed position at all times when not in use. Subpart BBBBBB does not require floating roofs for these tanks.

Subpart BBBBBB requires gasoline storage tanks at bulk terminals not meeting the exemption above to use one of the following control strategies:

1. Use of a fixed roof with an internal floating roof. The internal floating roof must use either a mechanical shoe seal, a liquid-mounted seal, or two seals (i.e., primary and secondary seals) mounted one above the other. Openings in the roof must be equipped with covers, lids, sleeves, gaskets, or similar seals.
2. Use of an external floating roof with both primary and secondary seals. The primary seal must be a mechanical shoe seal or liquid-mounted seal. Openings in the roof must be equipped with covers, lids, or seals.
3. Use of a closed vent system and control device designed to achieve 95% reduction of emissions.

(v) *National Emission Standards for Gasoline Distribution Facilities (Bulk Gasoline Terminals and Pipeline Breakout Stations)*, 40 C.F.R. Part 63, Subpart R contains requirements for petroleum storage tanks at bulk gasoline terminals which are major sources of HAP. (Note, no applicable facility exists in Maine.) Subpart R refers back to 40 C.F.R. Part 60, Subpart Kb (discussed earlier in this section) for requirements for petroleum storage tanks.

The Texas CEQ's Tier I BACT requires both IFRT and EFRT to have all uninsulated exterior surfaces exposed to the sun be aluminum in color or painted white. IFRTs must have a mechanical or liquid mounted primary seal or have a vapor mounted primary seal with a rim mounted secondary seal. EFRTs must have a mechanical or liquid mounted primary seal and a rim mounted secondary seal.

The South Coast AQMD BACT database has one entry for floating roof tanks. This determination applies to products similar to crude oil and other mixed petroleum products. The facility was required to utilize external floating roofs with geodesic dome covers. The tanks have metallic shoe primary seals, rim mounted secondary seals, and guide pole gasketed sliding covers with wipers.

The RBLC contains numerous entries for floating roof tanks (both internal and external) for products with vapor pressures above 0.5 psia. Floating roofs, both internal and external, are a common and expected tank design for storage of these products. There are a few instances where floating roofs appear to be indicated for tanks storing distillate fuel, but these are usually dual-purpose tanks, meaning they can store either distillate fuel or gasoline.

Almost all states that responded to our survey have some requirement to control emissions from tanks with capacities greater than 40,000 gallons that store products with a vapor pressure greater than 1.5 psia. Most states give facilities the option of utilizing a floating roof or installing a vapor capture and control system. None of the states surveyed have regulations requiring floating roofs for tanks which store products with vapor pressures below 0.5 psia.

<u>Summary</u>

Floating roofs, both internal and external, are a common and expected design for tanks that store gasoline and crude oil. Floating roofs are also sometimes required for tanks storing distillate fuel.

The use of floating roofs for tanks storing residual oil or asphalt was not addressed in any of the resources consulted. It is very likely that the viscous nature of these products and the need to keep the tanks heated and fully insulated result in technical problems in designing and operating floating roofs for these products.

In the references consulted, preference was given to floating roofs with a rim seal system with both primary and secondary seals, the use of gasketed sliding covers for all deck fittings, and welded deck seams.

It was unclear if any of the resources required a fixed roof in addition to a floating roof as IFRTs and EFRTs were equally represented. In most cases it appeared that the petroleum storage facility owner/operator was given the option of using either type of tank.

c. Variable Vapor Space Tanks

(1) Description

Variable vapor space tanks are equipped with expandable vapor reservoirs to accommodate vapor volume fluctuations attributable to changes in temperature and barometric pressure. 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.

(2) Emissions

Variable vapor space filling losses result when vapor is displaced by liquid during filling operations. Since the variable vapor space tank has an expandable vapor storage capacity, this loss is not as large as the filling loss associated with fixed roof tanks but is more than that associated with a floating roof tank. Loss of vapor occurs when the tank's vapor storage capacity is exceeded.

Variable vapor space tanks that rely on either a flexible diaphragm or a flexible coated fabric seal will have additional losses to the extent that vapors leak through or past the membrane used for the diaphragm or seal. The leakage rate through the membrane is a function of the permeability of the fabric material from which the membrane is manufactured, and a leakage rate past the membrane is a function of the leak tightness of the seam or seams where the membrane is attached to the tank wall. These leakage rates depend upon the type of fabric used for the membrane and the manner in which the membrane is attached to the tank wall.

(3) Potential Control Strategies

The use of a variable vapor space roof is itself a strategy for control of VOC emissions from the storage tank. The roof design is such that routine evaporative losses from the stored liquid are limited to the losses described above. No additional control strategies for this type of tank were found in the resources consulted for this report.

(4) Summary of Control Strategies in Use

As explained above, the use of variable vapor space roof is itself a strategy to control emissions of VOC from a petroleum storage tank.

The use of variable vapor space tanks is not common. They are for use with higher vapor pressure products but are less effective at controlling emissions than floating roof tanks. Therefore, new tank installations tend to require floating roofs over variable vapor space tanks. None of the resources consulted for this report contained information on variable vapor space tanks.

3. Product Distribution

a. Description

The transportation and marketing of petroleum products involves many distinct operations, each of which represents a potential source of VOC emissions. Petroleum storage facilities in Maine distribute their products to market primarily by loading them into tank trucks. However, products may also be distributed by loading railcars and ships and through pipelines. For simplicity, railcars, tank trucks, and marine vessels will be referred to collectively as cargo tanks.

Cargo tanks are loaded with product at the petroleum storage facility at a loading rack. At the loading rack, pipes are connected to or lowered into the cargo tank and used to fill the cargo tank with product.

b. Emissions

Loading losses are the primary source of VOC emissions from operations at cargo tank loading racks.

Loading losses occur as VOC in "empty" cargo tanks are displaced to the atmosphere by the liquid being loaded into the tanks. These VOC are a composite of (1) vapors formed in the empty cargo tank by evaporation of left-over product from previous loads, (2) vapors transferred to the cargo tank in vapor balance systems as product is being unloaded (e.g., gas station vapor balance systems), and (3) vapors generated in the cargo tank as the new product is being loaded.

The recent loading history of the cargo tank is an important factor in loading losses. The air inside the empty cargo tank is expelled when the tank is loaded. Cargo tanks are sometimes designated to transport only one product, known as “dedicated service.” However, cargo tanks may also be “switch-loaded” such that a less volatile liquid may be loaded and expel vapors remaining from a previous load of volatile product. If the cargo tank’s last load was a product with low volatility (e.g., distillate fuel), the VOC contained in the empty cargo tank’s vapor space will be significantly less than if the cargo tank’s last load was a product with high volatility (e.g., gasoline). Therefore, an understanding of the most recent previous load carried by the cargo tank is often as important as the product being loaded.

The quantity of evaporative losses from loading operations is, therefore, a function of the following parameters:

- Physical and chemical characteristics of the previous cargo;
- Method of unloading the previous cargo;

- Method of loading the new cargo; and
- Physical and chemical characteristics of the new cargo.

c. Potential Control Strategies

Following are control strategies for distribution of product at petroleum storage facilities:

(1) Submerged Fill

The principal methods used to load product into cargo tanks are splash loading and submerged fill.

In splash loading, the fill pipe dispensing the petroleum product is lowered only part way into the cargo tank. Significant turbulence and vapor/liquid contact occur during the splash loading operation, resulting in high levels of vapor generation and loss. If the turbulence is great enough, liquid droplets can be entrained in the vented vapors.

In submerged filling, the fill pipe opening is below the liquid surface level for most, if not all, of the time the cargo tank is being loaded. This is accomplished either by the submerged fill pipe method, where the fill pipe extends almost to the bottom of the cargo tank, or the bottom loading method, where a permanent fill pipe is attached to the cargo tank bottom. With submerged fill, liquid turbulence is significantly reduced, resulting in much lower vapor generation than splash loading.

(2) Vapor Balance

At gasoline stations, a delivery truck retrieves the vapors displaced in the underground storage tank when the truck is emptied. A similar operation can sometimes be performed at petroleum storage facilities. Vapors can be returned to the storage tank when the vapors inside the cargo tank are displaced during the filling operation.

Vapor balance alone has limitations. If the petroleum storage tank dispensing the product has a floating roof, there is no vapor space in the tank for the cargo tank vapors to be returned to. Returning vapors to a fixed roof tank may cause turbulence, which would increase emissions from the tank's vents. Therefore, vapor balance systems used at petroleum storage facility loading racks typically do not return the vapor to a storage tank, but instead deliver it to a control device such as those described below.

Residual fuel and asphalt are transported at high temperatures (150 - 300 °F). To ensure that the product stays hot during transport, special double-walled trailers or railcars are used. Due to the design of the cargo tanks, these products are "top-loaded." Top-loading involves lowering a fill pipe through a hatch in the roof of the cargo tank. These cargo tanks are not equipped to accommodate vapor balancing equipment.

(3) Vapor Recovery Units

Vapor recovery units (VRUs) route VOC-laden vapors to a device which separates the VOC from the exhaust stream. Depending on the design, the VRU may either trap/bind the VOC to a solid to be disposed of or recover the VOC back as a liquid that can be either disposed of or piped back to the petroleum storage tank. VRUs can be designed to achieve control efficiencies for VOC greater than 98%. VRUs recover the product in the displaced vapors by the use of adsorption or condensation.

(i) <u>Carbon Adsorption</u>

Carbon adsorption is the process of passing the VOC-laden air stream through a bed of adsorbent material, typically activated carbon, although other media may be suitable for certain applications. Hydrocarbons attach to the surfaces of the activated carbon particles.

Carbon adsorbers can be either regenerative or non-regenerative. With non-regenerative carbon adsorption, the adsorbent eventually becomes saturated and loses its effectiveness. The adsorbent needs to be periodically replaced and the spent material disposed of. Due to the cost to replace the spent media and the creation of an additional waste stream, non-regenerative carbon adsorption is not often utilized for high volume, high concentration streams, such as the vapor balance gas stream from gasoline loading.

With regenerative carbon adsorption, hydrocarbons are desorbed and collected, typically by drawing a vacuum on the sorbent bed or by using heated air, steam, or nitrogen. The recovered hydrocarbons can be returned to the petroleum storage tank. A drawback of this control approach is that the adsorbent typically binds strongly to heavy hydrocarbons and is less effective at capturing lighter organics such as propane. Therefore, it may be difficult to desorb some materials which can foul the adsorbent over time. Additionally, lighter materials are even more likely to pass through without being adequately collected if heavy hydrocarbons have already bound to the adsorbent. Therefore, regenerative carbon adsorption is typically used for VRUs associated with the loading of gasoline or distillate fuel and not with heavier hydrocarbon products such as crude oil, residual fuels, and asphalt.

(ii) Condensers

VOC can be removed from an air stream by condensing the product to a liquid. Condensation occurs when an exhaust stream that is saturated with product vapors undergoes a phase change from gas to liquid. The phase change can be achieved in two ways. The system pressure can be increased at a given temperature (i.e., compression), or the temperature may be lowered at a constant pressure (i.e., refrigeration).

For a more volatile product (i.e., a product with a low boiling point and high vapor pressure), larger amounts can remain in the vapor phase at a given temperature. To induce condensation, the exhaust stream must be cooled, compressed, or both. In general, it is more energy-intensive to operate a condenser to control a more volatile product (e.g., gasoline) than a less volatile product (e.g., distillate fuels). However, the less volatile products also often contain heavy, sticky compounds that can stick to the inside of a condenser, reducing its efficiency and effectiveness over time.

(4) Vapor Combustion Units

A vapor combustion unit (VCU) raises the temperature of the exhaust stream to oxidize (burn) the VOC components. VCUs can be designed to achieve control efficiencies for VOC greater than 98%. Types of VCUs include open flares, enclosed thermal oxidizers, and regenerative thermal oxidizers.

(i) Flares

Flaring is a type of thermal oxidizer that directs the VOC-laden exhaust stream through a vertical pipe to a burner assembly located well above ground level. VOC are burned in the open air using a specially designed burner tip, auxiliary fuel, and steam or air to promote mixing. Completeness of combustion in a flare is governed by flame temperature, residence time in the combustion zone, turbulent mixing of the components to complete the oxidation reaction, and available oxygen for free radical formation. Combustion is complete if all VOC are converted to carbon dioxide and water. Incomplete combustion results in some of the VOC being unaltered or converted to other organic compounds such as aldehydes or acids.

The flaring process can produce some undesirable byproducts including noise, smoke, heat radiation, light, sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and an additional source of ignition where not desired (i.e., fire hazard).

A major drawback to using an open flare for control of emissions from loading racks is the inability to conduct performance testing. Emissions from most loading racks, especially gasoline loading, are subject to state and federal regulations which establish emission standards, such as a limit on the amount of VOC that can be emitted per liter of product loaded. Due to its open nature, it is impossible to measure actual emissions of VOC after the control device, i.e., after the flame. Therefore, facilities which utilize a VCU for control of VOC emissions from loading racks typically use an enclosed thermal oxidizer instead of an open flare.

(ii) Enclosed Thermal Oxidizers

Enclosed thermal oxidizers (enclosed TOs), also known as ground flares, have burner heads which are inside an insulated shell. This equipment is located at ground level. The shell reduces noise, light, and heat radiation, and provides wind protection.

Enclosed TOs have a defined exhaust point which can be tested for control efficiency and compliance with emission limit regulations.

Enclosed TOs are most often used with exhaust streams with high concentrations of VOC, such as emissions from loading of gasoline. They are less cost-effective when used to control exhaust streams with lower concentrations of VOC. A recent analysis performed for a Maine facility indicated the cost of using a thermal oxidizing system for control of distillate vapors was approximately $600,000 per ton of pollutant controlled.

(iii) Regenerative Thermal Oxidizers

Regenerative thermal oxidizers (RTOs) preheat the inlet emission stream with heat recovered from the exhaust gases generated by their operation. The inlet gas stream is passed through preheated ceramic media and an auxiliary gas burner is used to reach temperatures between 1,450 ºF and 1,600 ºF at a specific residence time. The combusted gas exhaust then passes through a cooled ceramic bed where heat is extracted.

RTOs can very efficiently meet high destruction efficiencies of exhaust streams with a continuous, consistent VOC loading. However, short-term batch process, such as emissions from loading racks, are not well suited for control by an RTO. The intermittent nature of the emissions in the exhaust stream means there could be significant periods of time between high VOC loads, allowing the ceramic media to cool and fail to effectively or efficiently pre-heat the incoming gases. This would result in less efficient operation and the use of more auxiliary fuel.

d. Summary of Control Strategies in Use

(1) Gasoline Loading

Bulk gasoline plants and terminals are subject to state and federal regulations which set emission standards for gasoline loading racks at petroleum storage facilities.

Per *National Emission Standards for Hazardous Air Pollutants for Source Category: Gasoline Distribution Bulk Terminals, Bulk Plants, and Pipeline Facilities*, 40 C.F.R. Part 63, Subpart BBBBBB, bulk gasoline terminals with a gasoline throughput of 250,000 gallons per day or greater are subject to an emission standard for VOC of 80 milligrams per liter (mg/l) of product loaded. Although several facilities in Maine are subject to this standard, all of them are also subject to more stringent standards described below.

Facilities which are categorized as a major source of HAP are subject to an emission standard for VOC of 10 mg/l of product loaded per 40 C.F.R. Part 63, Subpart R. There are no facilities in Maine subject to this standard.

Pursuant to Maine state regulation 06-096 C.M.R. ch. 112, bulk gasoline terminals are subject to an emission standard for VOC of 35 mg/l of product loaded. Bulk gasoline terminals which are categorized as a major source of HAP are subject to an emission standard for VOC of 10 mg/l of product loaded.

Although no petroleum storage facility in Maine is considered a major source of HAP, roughly two thirds of Maine’s licensed facilities which distribute gasoline are subject to the 10 mg/l standard via restrictions incorporated through Best Practical Treatment (BPT) in their air emission license. This includes all three facilities in Maine which are licensed as major sources of VOC.

None of these standards can be met without employing emissions controls at the loading rack. Therefore, all bulk gasoline terminals in Maine operate either a VRU or VCU for control of VOC emissions from the loading of gasoline into cargo tanks.

Texas CEQ's Tier I BACT requires emissions from truck loading of products with vapor pressures greater than 0.5 psia (e.g., gasoline) to be routed to a VOC control device which meets a collection efficiency of 98.7%.

The South Coast AQMD BACT database has one entry for truck loading. This determination applies to products with a vapor pressure greater than 0.10 psia at 70° F (e.g., gasoline). The facility was required to install a thermal oxidizer (VCU) with an assumed overall control efficiency of 95%.

The RBLC contains numerous entries for truck/railcar loading of gasoline or other similar petroleum products which require submerged fill and routing of collected vapors to a VRU or VCU.

All states surveyed require some type of control for the loading of gasoline. Maine's level of control for gasoline loading is equivalent to, or more stringent than, the level of control required in other states surveyed.

(2) Distillate Loading

There are no state or federal regulations which address the control of emissions from loading distillate fuel into trucks or railcars.

Cargo tanks that carry gasoline may also be used to carry distillate fuel, a procedure known as "switch-loading." Since switch-loading can cause a cargo tank being filled with distillate fuel to have emissions similar to gasoline loading, the Department requires licensed petroleum storage facilities to either prohibit switch-loading (i.e., only load dedicated service trucks) or to capture the displaced vapors and route them to a control device (VRU or VCU). These requirements are incorporated into a facility's license under the authority of BPT. However, no such requirement exists for smaller petroleum storage facilities that fall below the Department's licensing thresholds.

The Texas CEQ Tier I BACT for the loading of trucks or railcars with products whose vapor pressure is less than 0.5 psia requires submerged fill or bottom loading of the cargo tank.

The RBLC contains three entries[39] that include emissions from the loading of distillate fuel. The emission limits associated with these entries are equivalent to those for submerged filling without any additional control device. These limits also assume or require the trucks be "dedicated service," i.e., that they carry only distillate fuel and not any other petroleum products.

[39] RBLC IDs IN-0231, IN-243, and IN-0244

The RBLC contains one entry[40] for 15 loading racks, both truck and railcar, for distillate fuels which required the collection of the displaced gases and routing them to a thermal oxidizer.

There are several RBLC entries that reference distillate fuel products in conjunction with gasoline loading. In those cases, it was impossible to determine whether the controls listed would have been required for distillate fuels alone.

Many states (including Arkansas, Delaware, Illinois, Indiana, Iowa, Louisiana, Maryland, Minnesota, Texas, Washington, and Wisconsin) do not require emissions from the loading of distillate fuel to be controlled unless the truck's most recent previous load was gasoline (i.e., switch loading). However, facilities may often elect to control these emissions as a way to reduce facility emissions below certain permitting thresholds. Some states (including Georgia, Hawaii, and New York) require emissions from all distillate loading to be controlled, typically by a VCU or VRU.

(3) Residual/Asphalt Loading

There are no state or federal regulations which address the control of emissions from loading residual fuel or asphalt into trucks or railcars.

The Texas CEQ Tier I BACT for the loading of trucks or railcars with products with a vapor pressure less than 0.5 psia requires submerged fill or bottom loading of the cargo tank. Note: This is from a Texas CEQ guidance document and not a state regulation.

The RBLC contained only one entry[41] that addressed loading rack emissions for residual fuel. A petroleum storage facility in Chelsea, Massachusetts installed a VCU to control emissions from this process. This control was added at the request of the petroleum storage facility to ensure the facility would continue to be considered a minor source. The system is assumed to have a capture efficiency of 90% and a destruction efficiency of 99% for a combined total control efficiency of 89%.

There were no RBLC entries that addressed product loading of asphalt.

In their response to our survey, the State of Michigan indicated that emissions from the loading of asphalt are sometimes controlled, primarily to reduce odors. The State of North Carolina also indicated that controls on asphalt loading racks are sometimes installed for odor control purposes. No other

[40] RBLC ID AZ-0046
[41] RBLC ID MA-0040

states reported requiring or considering controls on the loading of residual or asphalt products.

(4) Crude Oil Loading

None of the petroleum storage facilities in Maine load crude oil into cargo vessels. The one facility that stores crude oil offloads from marine barges and transfers the product out of the facility via pipeline. Therefore, cargo loading for crude oil was not investigated as part of this study.

(5) Marine Vessel Loading

There are no state or federal regulations which address the control of emissions from loading marine vessels for products with vapor pressures less than 1.5 psia (e.g., distillate fuels, residual fuels, asphalt).

National Emission Standards for Marine Tank Vessel Loading Operations, 40 C.F.R. Part 63, Subpart Y, applies to marine loading of products with vapor pressures greater than 1.5 psia (e.g., gasoline). Below is a summary of Subpart Y requirements.

(i) Area (minor) Sources of HAP Constructed Prior to 1999

Subpart Y requires use of submerged fill.

Maine has one facility which is licensed for marine vessel loading in this category. In addition to submerged fill, the facility is required to capture vapors from the loading of gasoline and route them to a VCU for destruction.

(ii) Area (minor) Sources of HAP Constructed After 1999 and All Major Sources of HAP

Facilities in this category must load only vapor-tight marine vessels. Vapors from marine loading must be collected and controlled (e.g., through use of a VCU or VRU) by 97% for existing major sources and 98% for area sources or new major sources. Maine has no marine loading facilities in this category.

Texas CEQ’s Tier I BACT requires emissions from marine vessel loading of products with vapor pressures greater than 0.5 psia (e.g., gasoline) to be routed to a VOC control device. There are no requirements listed for marine vessel loading of products with vapor pressures less than 0.5 psia.

The South Coast AQMD BACT database does not contain any entries for marine loading.

There are several RBLC entries that reference marine vessel loading. These entries typically require collection of the displaced vapors and control through use of a VCU or VRU. However, the product being loaded is often not specified, and when it is, is typically gasoline or crude oil, both products with a vapor pressure greater than 1.5 psia. Many entries reference compliance with 40 C.F.R. Part 63, Subpart Y and the requirements listed above.

The State of New York requires facilities which transfer less than 15,000 gallons per day through marine vessel loading to use a vapor balance system. Facilities which transfer more than 15,000 gallons per day through marine loading are required to utilize emission controls with at least a 90% reduction efficiency.

4. Miscellaneous Emissions

Following are additional sources of VOC emissions from petroleum storage facilities not addressed elsewhere:

a. Facility Piping

Operation of a petroleum storage facility equipment will result in some amount of unavoidable fugitive VOC emissions from facility piping, valves, pumps, and other components. Best practices for minimizing these emissions include regular inspections of all facility piping components to check for leaks and/or required maintenance.

b. Roof Landings and Tank Cleanings

(1) Description of Emissions

Floating roof tanks need to be periodically emptied to perform maintenance and required inspections of the tank interior.

When using floating roof tanks, the roof floats on the surface of the liquid inside the tank and reduces evaporative losses during routine operations. However, when the tank is emptied to the point that the roof lands on deck legs or hangers, the roof is no longer floating, and the tank behaves like a fixed roof tank.

After the floating roof is landed, as the liquid level in the tank continues to drop, a vacuum is created which could cause the floating roof to collapse. To equalize the pressure and prevent damage, a breather vent (vacuum breaker) is activated, allowing a vapor space to form between the floating roof and the liquid. The breather vent may remain open until the roof is again floated, so whenever the roof is landed, vapor can be lost through this vent as well as through other deck fittings and past the rim seal. Even in the case of a self-closing breather vent, the vapor space beneath the floating roof is vented via the other deck fittings and the rim seal, which is effectively rendered vapor mounted once the liquid level drops below the bottom of the rim seal. These losses are called “standing idle losses.”

The three different mechanisms that contribute to standing idle losses are (1) breathing losses from vapor space; (2) wind losses; and (3) clingage losses. The specific loss mechanism is dependent on the type of floating roof tank and the bottom condition.

For IFRTs or domed EFRTs with liquid remaining in the bottom (liquid heel), the breathing losses originate from a discernible level of liquid that remains in the tank. This is typically the case for IFRTs or domed EFRTs with nominally flat bottoms (including those built with a slight cone), due to the flatness of the tank bottom and the position of the withdrawal line. If the remaining liquid covers the entire bottom of the tank, it is known as a full liquid heel. The liquid evaporates into the vapor space beneath the landed floating roof and daily changes in ambient temperature cause this vapor space to breathe in a manner similar to that seen in a fixed roof tank. A partial liquid heel may be left in tanks with sloped bottoms if the withdrawal of liquid ceases while some free-standing liquid remains in a sump or elsewhere in the bottom of the tank.

For EFRTs, which are not fully shielded from the surrounding atmosphere, wind action across the landed floating roof can create a pressure differential that may cause vapors to flow from beneath the landed floating roof. The higher the wind speeds, the more vapor that can be expelled. These are known as wind losses.

For tanks with a cone-down or shovel bottom, the floor of the tank is sloped to allow for more thorough emptying of the tank contents. Therefore, the amount of liquid remaining may differ significantly from tanks with flat bottoms; see Figure 21.

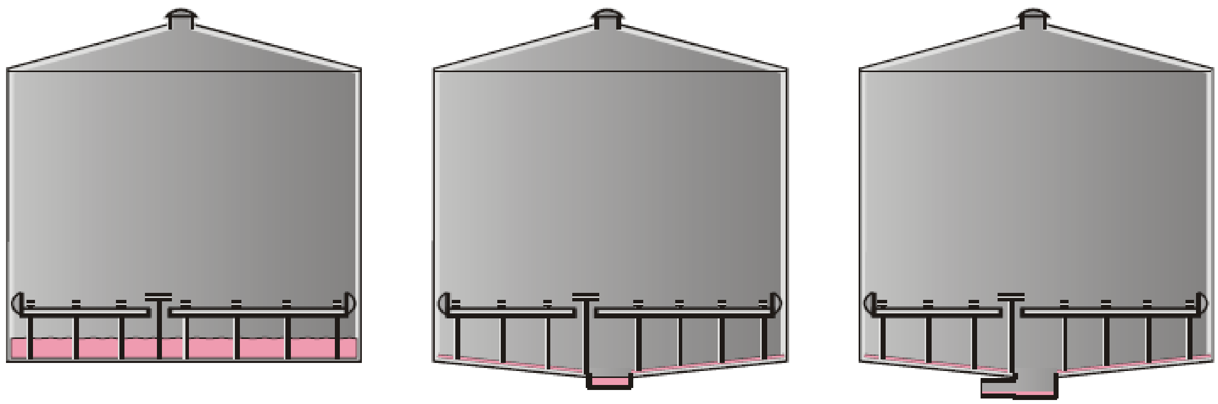

Figure 21:Bottom conditions for landing loss.[42]

Full Liquid Heel	Partial Liquid Heel	Drain-Dry
Standing liquid across the entire bottom	Standing liquid only in or near a sump; clingage elsewhere	No standing liquid, only liquid is clingage

When the emptying operation drains the tank bottom but leaves a heel of liquid in or near the sump, the tank is considered to have a partial liquid heel. A drain-dry condition is attained only when all of the standing liquid has been removed, including from the bottom of the sump. However, due to sludge buildup, irregularity of the tank bottom and roughness of the inside of the tank, a small layer of liquid can remain clinging to the sloped bottom of a drain-dry tank. This layer of liquid will create vapor that can result in clingage losses.

After the tank has been emptied, before inspection or maintenance can be performed, the interior tank vapor space must be purged (also known as cleaning or degassing) to create a safe working environment. The vapor space is purged via forced ventilation using fans or blowers either at the top of the tank or at a shell manhole, cleanout fitting, or other shell fitting. The first exchange of air (i.e., the first volume of air equivalent to the interior tank volume) will have the highest level of VOC. Subsequent air exchanges will have lower concentrations of VOC, but emissions will continue to occur until tank cleaning is complete.

If the tank is subsequently refilled after the inspection or maintenance is complete, there will be vapors generated by the incoming product which would then be expelled from the tank by the rising liquid level. For a fixed

[42] Courtesy of R. Ferry, TGB Partnership, Hillsborough Hurdle Mills, NC.

roof tank, these refilling emissions are the same as routine working (filling) losses. For a floating roof tank, these emissions are similar to those of a fixed roof tank until the product reaches the level where it makes contact with the roof and the roof is floated off its legs or hangers, at which point they will return to normal levels of operational losses for a floating roof tank.

(2) Potential Control Strategies

(i) Drain-Dry Design

When a drain-dry tank has been emptied, the only stock liquid available inside the tank is a thin layer that clings to the wetted surface of the tank interior. The slope prevents a significant amount of stock liquid from remaining in the tank so that evaporation is much lower than from tanks with liquid heels. Due to the limited amount of liquid clinging to the interior of the tank there would be no liquid remaining to replenish vapors once the clingage layer has evaporated.

(ii) Vapor Control

Emissions from tank cleaning or purging can be routed to either a temporary or permanently installed control device such as a VCU or VRU. The forced ventilation causes a flow through the tank which can be captured and directed to a control device such as a flare.

(3) Summary of Control Strategies in Use

Maine DEP regulation *Petroleum Liquid Storage Vapor Control*, 06-096 C.M.R. ch. 111, requires floating roof tanks to undergo a complete inspection at least once every ten years. This inspection requires the tank to be emptied and degassed. However, facilities are prohibited from emptying and degassing a tank for the purposes of a complete inspection between June 1 and August 31 of each year to limit VOC emissions during the height of the ozone season.

Both *Standards of Performance for Storage Vessels for Petroleum Liquids for Which Construction, Reconstruction, or Modification Commenced After May 18, 1978, and Prior to July 23, 1984*, 40 C.F.R. Part 60, Subpart Ka, and *Standards of Performance for Volatile Organic Liquid Storage Vessels (Including Petroleum Liquid Storage Vessels) for Which Construction, Reconstruction, or Modification Commenced After July 23, 1984*, 40 C.F.R.

Part 60, Subpart Kb, require the roofs of applicable tanks to be floated on the surface of the liquid at all times except when the tank is to be fully emptied.

Texas CEQ's Tier I BACT addresses emissions from the draining and cleaning of fixed and floating roof tanks in a similar manner. If there is any standing liquid within the tank, and the vessel is opened to the atmosphere or ventilated, the vapor stream must be controlled until there is no standing liquid or the VOC vapor pressure is less than 0.02 psia. New floating roof tanks must be designed to drain dry. Degassing (purging) of floating roof tanks must commence within 24 hours of landing. However, bulk gasoline terminals are allowed two uncontrolled landings per tank per year to accommodate any required switching of the type of gasoline stored (i.e., switching between summer and winter gas).

The South Coast AQMD BACT database has one entry for control of emissions from tank degassing. This determination applies to a degassing of tanks containing non-chlorinated petroleum hydrocarbon vapors. The control utilized is a thermal oxidizer capable of 99.9% destruction efficiency.

The RBLC contains numerous entries where tanks are required to capture emissions from tank degassing and route them to a control device, typically a VCU or VRU. These requirements appear to be intended mostly for tanks storing products with a vapor pressure greater than 0.5 psia. The control devices typically achieve greater than 99% control. Degassing is required to commence within 24 hours of the roof being landed on its legs or hangers (to minimize the amount of time the tank behaves as a fixed roof tank) and controls are required to be operated during the purging operation until the VOC concentration in the exhaust stream falls below 5,000 – 10,000 parts per million (ppm) depending on the specific determination. New tanks in the RBLC are often required to be built with a drain-dry design.

c. Heating Equipment

VOC emissions from the petroleum storage facility's heating equipment are due to any incomplete combustion of the fuel burned for heating. Such emissions are typically very low and managed by efficient operation, which is ensured by performing regular tune-ups of the heating equipment.

d. Control Equipment

Equipment to control VOC emissions may itself be a source of VOC or other pollutants.

VCUs destroy VOC emissions by burning them, releasing emissions of other pollutants which are products of combustion such as particulate matter, sulfur dioxide, nitrogen oxides, and carbon monoxide. Additionally, a VCU must always maintain a pilot flame. If the concentration of the VOC in the exhaust stream is extremely low, additional assist fuel may need to be burned to maintain the pilot light.

VRUs typically adsorb VOC onto another medium such as carbon. If the carbon is not regenerated, it becomes a solid waste that must be disposed of, potentially off-gassing the VOC in another location. If the VRU is a regenerative unit which uses heat to desorb and regenerate the media, a fuel is usually burned to create that heat, which again emits products of combustion.

IV. Methods for Controlling Odors from Petroleum Storage Facilities

A. Background and Evaluation of Odor Regulations in the U.S.

Petroleum products are often associated with distinctive smells or odors. Besides their visual presence, petroleum storage tanks most often garner attention because of associated odors or, as one European study states, "discomfort … due to olfactory annoyance."[43] Odor is not regulated by the U.S. EPA. Some state and local jurisdictions do regulate nuisance odor, including some regulating odors from specific source categories. For example, the Department's *Solid Waste Management Rule for Processing Facilities*, 06-096 C.M.R. ch. 409, includes a standard to assess a nuisance odor from facilities that process wastewater treatment sludge and septage using a modified n-butanol 5-point odor intensity referencing scale.

As part of this project, the Department surveyed each state and, where appropriate, sub-state jurisdictions (for example, California has numerous air quality control districts within the state). The Department received 35 responses to the survey, 32 of which provided answers to questions regarding the regulation of odor. Of the respondents, 10 indicated they had no odor regulations in place. A review of the odor regulations from the 22 respondents with odor regulations in place showed that most considered odor to be a "nuisance" consideration and the requirements were mostly subjective.

Examples of requirements from some of these regulations include the following:

- Prohibiting "unreasonable interference with the comfortable enjoyment of life and property" (MI);
- Defining air pollution as one or more contaminants that "…unreasonably interfere with the enjoyment of life or property." (IL);
- Prohibiting "…the emission of any substance or combination of substances which creates or contributes to an odor beyond the property boundary of the premises that constitutes a nuisance." (CT);
- Prohibiting the cause or allowance of "the emission of an odorous air contaminant such as to cause a condition of air pollution," with possible methods of compliance including scentometer tests, air quality monitoring, and affidavits from citizens and investigators. (DE); and

[43] Invernizzi M., Ilare J., Capelli L., Sironi S., 2018, Proposal of a method for evaluating odour emissions from refinery storage tanks, Chemical Engineering Transactions, 68, 49-54 DOI: 10.3303/CET1868009

- Requiring no detectable odors when odorous air is diluted with seven or more volumes of odor-free air for residential areas, no detectable odors when odorous air is diluted with 16 or more volumes of odor-free air for other land use areas. (CO).

These regulations are seemingly subjective and therefore difficult to enforce, because what is considered “unreasonable,” a “nuisance,” “interference,” “enjoyment,” or “odor-free” will vary from person to person.

More specific and yet still subjective examples of odor regulation come from North Carolina and North Dakota:

- “Objectionable odor” means any odor present in the ambient air that by itself, or in combination with other odors, is or may be harmful or injurious to human health or welfare or may unreasonably interfere with the comfortable use and enjoyment of life or property. Odors are harmful or injurious to human health if they tend to lessen human food and water intake, interfere with sleep, upset appetite, produce irritation of the upper respiratory tract, or cause symptoms of nausea, or if their chemical or physical nature is, or may be, detrimental or dangerous to human health. (NC)
- An odor will be considered objectionable when a department certified inspector or at least 30% of a randomly selected group of persons, or an odor panel (five individuals certified in odor detection) exposed to the odor would deem that odor objectionable if the odor were present in their place of residence. (ND)
- An “odor concentration unit” is defined as a volume of odor-free air mixed with an equal volume of odorous air such that the combination would be at the threshold level of the olfactory senses. The intensity of an odor is determined by the ratio of the volume of odor-free air that must be mixed with a standard volume of odorous air so that a department-certified inspector or at least fifty percent of an odor panel can still detect the odor in the diluted mixture. (ND)

Rhode Island’s odor regulation prohibits emissions into the atmosphere of air contaminants which create an objectionable odor beyond the entity’s property line. It further specifies that a staff member of the Department shall determine by personal observation if an odor is objectionable, taking into account its nature, concentration, location, duration, and source. Pursuant to this regulation, odor controls consisting of a mist eliminator and carbon absorber were required to be added to the heated tanks at a petroleum storage facility in Providence, RI.

B. VOC vs. Odor

VOC are emitted as gases from certain solids or liquids. Title I of the CAA defines VOC as compounds containing carbon which participate in atmospheric photochemical reactions, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate. An alternate definition provided by the EPA regards VOC as all organic compounds having a vapor pressure exceeding 0.1 mm Hg at standard conditions (20 °C and 760 mm Hg). VOC include a variety of chemical compounds, some of which may have short- and long-term adverse health effects. VOC concentration can be measured, usually in ppm, using standardized test methods and procedures such as EPA Method 25A[44].

Odor can be defined as the sensation created by stimulating the olfactory organs[45] found in the nasal cavity. Odor perception has four major dimensions: threshold, intensity, character, and hedonic tone.

- **Odor threshold** is the lowest concentration of a substance that can be detected by human olfaction. Threshold values are unique for each potentially odorous compound, and they are not fixed physical constants but can vary from one individual to the next.
- **Odor intensity** is the perceived strength of the odor sensation and increases as a function of concentration.
- **Odor character** is what the substance smells like. ASTM publication (ASTM data series DS 61, 1985) provides character profiles for 180 chemicals using a 146-descriptor scale, such descriptors including "fishy," "nutty," "creosote," "turpentine," "rancid," "sewer," 'ammonia," and "bananas." Since odor character can change with intensity, the odor characterization may differ from source to source or from person to person, depending on their individual sensitivity to a given odor.
- **Hedonic tone** is a category of judgment of the relative pleasantness or unpleasantness of an odor. Perception of hedonic tone is influenced by subjective experience, frequency of occurrence, odor character and intensity, and duration. Perceptions vary widely from person to person and are strongly influenced by external factors such as emotions, previous experiences, etc.[46]

Common odor problems are often caused by mixtures of highly volatile compounds with very low threshold detection limits in low concentrations in ambient air. Odors can also be caused by sulfur-containing compounds such as hydrogen sulfide (H_2S). These sulfur-containing compounds also have very low threshold detection limits but are not VOC. VOC and odor are often linked, because many VOC are odorous. However, not all VOC emit odors, and not all odors are caused by VOC.

[44] See 40 C.F.R. Part 60, Appendix A, Method 25A, *Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer*.
[45] Medical Definition of *olfactory organ*: an organ of chemical sense that receives stimuli interpreted as odors from volatile and soluble substances in low dilution, that lies in the walls of the upper part of the nasal cavity. "Olfactory organ." *Merriam-Webster.com Medical Dictionary*, Merriam-Webster, https://www.merriam-webster.com/medical/olfactory%20organ. Accessed 4 Nov. 2020.
[46] Murnane, S. S., Lehocky, A. H., Owens, P. D. (2013). Odor Thresholds for Chemicals with Established Occupational Health Standards (2nd Edition). *American Industrial Hygiene Association (AIHA)*. Retrieved from https://app.knovel.com/web/toc.v/cid:kpOTCEOHS 7/viewerType:toc/

Many manufacturing sectors produce gases that contain odorous compounds, including synthetic flavoring manufacturing, paints and coatings manufacturing, paper mills, pharmaceutical industries, and refineries. Odorous components of natural origin are mainly released by industries such as slaughterhouses, breweries, bio-industries, textile industries, coffee roasting plants, yeast and alcohol factories, sewage treatment plants, and solid waste composting facilities.[47]

Perception of a mixture of odorous compounds may be different than perception of individual compounds. Odorous compounds have the potential to interact in an additive fashion, as counteractants (one cancelling out the perception of another), as maskants (one masking the detection of another), or two or more compounds together synergistically amplifying overall perception.

Measurement of odorous compounds is a technological challenge which has not been fully resolved. Olfactometers are instruments that still include human subjectivity to detect and measure ambient odors. To use an olfactometer, an operator controls the sample delivery while the test subject inhales through a sniffing port to detect the presence of odor. Most olfactometers are used in a laboratory setting, but a portable unit, The Nasal Ranger® (St. Croix Sensory, St. Elmo, MN), is available for field use.[48] These devices are not common and still include subjective evaluation by a test subject.

In Europe, there is a standardized method to assess the odor concentration of a gas mixture, EN 13725:2003, using dynamic olfactometry. This method of analysis uses a dilution instrument (olfactometer) to present a specific odor to a panel of trained personnel. The measurement is based on the sensation perceived by the panel and is expressed in units of odor per cubic meter of neutral air (ou_E/m^3). This number is then used with the gas emission flow rate to define the odor emission rate (OER), expressed in ou_E/s. First, though, the maximum potential odor emission rate must be established for each petroleum storage tank. The variability of tank composition, emission periods, corresponding flow rates, and individuals' odor perceptions are all very practical constraints to the use of this method.

Some chemical compounds that contribute to odors associated with petroleum products include butenes, octane, p-tert-butyl toluene, heptanes, hexane, hexene, naphthalene, nonane, and methylcyclohexane.[49] While some of these odorous chemical compounds are pollutants regulated by EPA and the State of Maine, many either have no associated health-based, Maine Ambient Air Guideline (AAG)[50] value or have odors that can be

[47] Revah S., Morgan-Sagastume J.M. (2005) Methods of Odor and VOC Control. In: Shareefdeen Z., Singh A. (eds) Biotechnology for Odor and Air Pollution Control. Springer, Berlin, Heidelberg. https://doi.org/10.1007/3-540-27007-8_3
[48] Murnane, S. S., et al.
[49] Murnane, S. S., et al.
[50] The Maine Center for Disease Control & Prevention (ME-CDC) develops Ambient Air Guidelines (AAGs) to assist risk managers and the public in making decisions regarding the potential human health hazards associated with chemicals in air. AAGs are not promulgated by rule-making and therefore are not issued as legally enforceable ambient air "standards." Rather, AAGs represent the most recent recommendations for chemical concentrations in

detected at levels significantly lower than their associated AAG. In addition, some of these odorous compounds are not hazardous air pollutants regulated by either the EPA or the State of Maine.

C. Potential Controls

Potential controls for mitigation of odorous compounds from petroleum storage tanks include demisters, carbon beds, biofiltration, thermal oxidizers, and odor masking materials. Several of these control technologies have been discussed previously in this report where VOC controls are addressed. The same possibilities and constraints apply to the use of these technologies for odor control. Biofiltration and odor absorption materials will be discussed in this section.

There is currently no technology routinely applied to mitigate odors from heated petroleum storage tanks storing #6 fuel oil and asphalt. Although there are some specific locations using add-on controls such as demisters and carbon beds, the effectiveness of such controls is not well documented, in part because these technologies are not widespread in the industry and thus have not been thoroughly evaluated for measurable effectiveness. In addition, difficulties in the full and accurate characterization of odorous compounds and quantification of their emission rates provide challenges to the design of effective odor controls.

Additional hinderances to the development of standard odor control technologies for petroleum storage tanks have been identified by researchers who have found no direct correlation between a mixture's chemical composition and its effective olfactory properties (Rice and Koziel, 2015)[51]. This phenomenon is explained by the existence of chemical and physical interactions between various compounds present in odorous mixtures, such that actual olfactory effects may be greater or lesser than the sum of the contributions of the individual substances (Zhao et al., 2014)[52]. Based on the odor contributions of certain compounds, the results of one study revealed that propanol, toluene, and hydrogen sulfide were the dominating odor-causing emissions of industrial facilities included in the study (landfill, WWTP, rendering plant, and ambient air in a town with large petroleum and petrochemical industries).[53]

ambient air, below which there is minimal risk of a deleterious health effect resulting from long-term inhalation exposure.

[51] Rice, S., Koziel, J.A., 2015. The relationship between chemical concentration and odor activity value explains the inconsistency in making a comprehensive surrogate scent training tool representative of illicit drugs. Forensic Sci. Int. 257, 257–270.

[52] Zhao, P., Liu, J.M., Tang, S.C., 2014. The Interaction of Mixing Odorants with Similar Chemical Properties: A Case Study on Ketone Compounds, in: Advanced Materials Research. pp. 32–37.

[53] Dincer, F., Muezzinoglu, A. (2006). Chemical characterization of odors due to some industrial and urban facilities in Izmir, Turkey. *Atmospheric Environment*, *40*(22), 4210-4219. doi:10.1016/j.atmosenv.2005.12.067

1. Biofiltration

Biofiltration can effectively remove biodegradable odorous compounds from gas streams. In a biofilter, the exhaust gas stream is humidified, then passed through a distribution system beneath a bed of compost, bark mulch, or soil. The media in the bed contains an active population of bacteria and other microbes. As the air stream flows upward through the media, pollutants are adsorbed into the media and converted by microbial metabolism into carbon dioxide and water. In an ideal biofiltration scenario, this technology boasts low capital and operating costs, low energy requirements, and an absence of residual materials requiring further treatment or disposal. Biofiltration controls have been successfully applied to a range of industrial and public sector sources for the abatement of odors, with a purported elimination efficiency of more than 90%, according to manufacturers of biofiltration units.[54]

Biofilters work best at steady state conditions and cannot tolerate extended periods of downtime. Petroleum storage tanks do not provide those conditions. Controlling tank working losses means large concentration swings, and tank loading does not occur as steady-state operation. Living organisms are crucial to the successful function of biofilters, and freezing temperatures would kill these organisms and, as such, the effectiveness of this control option. Biofilters also typically require a very large footprint which is not always available in retrofit scenarios.

The successful engineering of a solution to any problem requires clear and accurate definition of the problem and of the desired outcome. Because petroleum products stored in heated tanks, namely #6 oil and asphalt, are each a mixture of several compounds with specific compositions varying from tank to tank and from delivery to delivery, the exact composition of odorous compounds emitted from these tanks will vary. This variation in the target compounds to be removed from tank exhaust gases increases the difficulty in designing the most effective control for each tank.

To identify an appropriate control method for emissions of odorous compounds, it is crucial to consider the physical, thermodynamic, and reactive properties of the compounds and the controls. For example, results of a field study of the use of biofiltration to treat volatile hydrocarbons from petroleum suggest that the effectiveness varies greatly between compounds. Typically, more than 95% of aromatic compounds, such as benzene and reduced sulfur compounds, can be removed using residence times in the biofiltration unit of one minute or less, while removal of any more than 70% of light aliphatics would require a residence time of several minutes, which would thus require correspondingly larger biofilter volumes

[54] Altaf H. Wani, Richard M.R. Branion & Anthony K. Lau (1997) Biofiltration: A promising and cost-effective control technology for Odors, VOCs and air toxics, Journal of Environmental Science and Health . Part A: Environmental Science and Engineering and Toxicology, 32:7, 2027-2055, DOI: 10.1080/10934529709376664

with higher capital costs. This comparison shows that the composition of gases coming from a petroleum storage tank is critical in the selection and design of the most effective control option or combination of options for that tank. Additional considerations are the appropriate selection of filter material, the reliability of the moisture control system, and the level of fluctuation in concentrations of compounds to be removed from the gaseous exhaust.[55] The number and variation of components in the exhaust stream further complicate these considerations.

2. Odor Masking Materials

Some applications, such as landfills, use odor masking materials along the fence line. Such materials are available as liquid to spray or as granules to sprinkle on the ground around property perimeters or to put into socks and hang at intervals around the fence line for the wind to blow through. One such product, Ecosorb ® claims "a proprietary blend of oils including those from pine, aniseed, clove, lime and other sources" to "tackle the toughest smells…" and is billed as an "odor eliminator." Outside of vendor advertising, research found no independent analysis of the effectiveness of such materials for controlling odors from petroleum storage tanks.

[55] Leson, G. and Smith, B., 1997. Petroleum Environmental Research Forum Field Study On Biofilters For Control Of Volatile Hydrocarbons. [online] Journal of Environmental Engineering / Volume 123 Issue 6 - June 1997. Available at: <https://doi.org/10.1061/(ASCE)0733-9372(1997)123:6(556)> [Accessed 30 September 2020].

V. Methods of Determining Emissions

A. Background Information: Historical Emissions Estimation Methods

Emissions from air pollution sources, such as industrial boilers and processes, are typically calculated from the measured concentration of a given pollutant in the exhaust stream and the measured flow rate from the emissions source. Direct measurement of emissions from liquid storage tanks is difficult due to the generally low flow rates of the exhaust stream during normal tank operation. Therefore, emissions from liquid storage tanks are generally estimated through the use of equations developed using theoretical energy transfer models. These calculations, developed by the American Petroleum Institute, use information about the tank configuration, tank operation (e.g., throughput, heating, roof landings, cleanings, etc.), properties of the product(s) being stored, and local climate to estimate emissions. The methodology for performing these calculations has been published by EPA in AP-42, *Compilation of Air Pollutant Emissions Factors*, Chapter 7. EPA also published a software program called TANKS designed to assist in calculating emissions from storage tanks using the AP-42 methodology; however, the software contains known errors and is no longer receiving updates or support. Despite this, until recently, TANKS was still commonly used to calculate annual emissions from liquid storage tanks.

Emission sources at petroleum storage facilities other than liquid storage tanks include product distribution, heating equipment, and control equipment. Emissions from these sources are more suitable to direct measurement through testing or estimation by simple and well-established emission factors than storage tanks, and do not require the same use of complex calculations based on theoretical models.

B. Physical Testing vs. Calculating Emissions

Possible methods of determining emissions from petroleum storage facilities are as follows:

- Testing of the facility’s emissions units to develop site-specific emission rates (e.g., pounds of pollutant per hour);
- Calculating emissions using models or complex formulas which take into account the physical properties of the tanks and the products stored;
- The use of continuous emissions monitoring systems (CEMS); and
- The use of forward-looking infrared (FLIR) technology.

The advantages and disadvantages of each method are described below.

1. Physical Testing of Tank Emissions

Testing involves drawing a sample (grab or continuous) from an exhaust stream of an emissions unit or process and analyzing it to determine the concentration of the pollutant(s) of interest. Analysis methods vary, depending on the type of emissions unit and the pollutant(s) of interest. Testing also typically involves measuring the flow rate of the exhaust stream (e.g., flow in cubic feet per minute). Once both the concentration and flow rate are known, the pollutant emission rate (e.g., lb/hr) can be determined.

a. Available Test Methods and Their Limitations

EPA has promulgated test methods, called reference methods, which are used to quantify emissions and demonstrate compliance with both federal and state emission standards[56]. For a liquid storage tank, the typical procedure is to measure vapor pressure in the space inside the tank above the liquid surface. From that vapor pressure measurement and the known vapor pressure of the target pollutant, the concentration of the target pollutant can be calculated.

In any container with material in both liquid phase and gaseous phase, such as petroleum storage tanks, molecules at the gas-to-liquid interface (the liquid surface) will constantly be transitioning from liquid phase to gaseous phase and from gaseous to liquid. The vapor pressure of a substance is the pressure exerted by its particles in the gaseous phase in thermodynamic equilibrium with its liquid phase at a given temperature in a closed system. The equilibrium vapor pressure is an indication of a liquid's evaporation rate. The pressure exhibited by vapor present above a liquid surface is known as vapor pressure.[57]

Potential methods to measure actual emissions of VOC include EPA reference method (RM) 2, *Velocity – S-type Pitot*; RM 25A, *Gaseous Organic Concentration – Flame Ionization*; and RM 18, *Volatile Organic Compounds – Gas Chromatography*. RM 2 is used to measure flowrate. RM 25A is used to determine a generic (single value equivalent) VOC value in terms of propane, methane, or other compound, depending on how the instrumentation is calibrated. RM 18 is used to determine methane concentrations, to be subtracted in order to calculate the NMHC (non-methane hydrocarbons) emission rate.

---

[56] See https://www.epa.gov/emc/emc-promulgated-test-methods for a full list of EPA's Air Emission Measurement Center's Promulgated Test Methods and links to each method.
[57] https://chem.libretexts.org/Bookshelves/General_Chemistry/Book%3A_Concept_Development_Studies_in_Chemistry_(Hutchinson)/13%3A_Phase_Equilibrium_and_Intermolecular_Interactions#:~:text=The%20situation%20is%20%22equilibrium%22%20in%20that%20the%20observable,of%20the%20liquid%20and%20gas%20do%20not%20change.

Although these reference methods are available, obtaining accurate and reproducible test results from petroleum storage facilities is difficult. Some of the reasons are discussed below.

- Flow rates from normal tank operation (during periods when stored material is not being added or removed from the tank) are lower than the calibrated instrumentation can accurately detect and measure. Most emissions testing from stationary sources is conducted on a source with a continuous, measurable flow. Petroleum storage tanks do not have such flow characteristics. During filling, the tank will demonstrate a flow outward, and while filling trucks, some flow inward. Beyond that, flow can be influenced by wind, solar effects, and ambient temperatures; factors that are both variable and uncontrollable. These flow rates are low enough that they are typically not measurable by EPA Reference Method 2.
- Some of the heavier compounds found in residual oil and asphalt products are problematic in sampling, as they can 'coat' the interior surfaces of the sampling train and equipment, making it difficult to acquire a true value.
- Physical characteristics of asphalt and residual oil products are incompatible with vapor pressure testing methods. Specifically, there is no certified laboratory analysis method for determining vapor pressure from asphalt. Calculated and/or assumed vapor pressure numbers are often used due to the high level of difficulty in obtaining meaningful and repeatable vapor pressure test results using ASTM D2879, the ASTM[58] method listed for determining vapor pressure from #6 fuel oil.

  ASTM D2879 is a laboratory test method that requires the sample being tested be placed in glassware, mostly thin glass tubes with U-bends. At specific temperatures and pressures, the liquid levels inside the glass must be measured very precisely to determine the vapor pressure. An error in measurement can cause the resulting vapor pressure to be off by a significant amount, especially for materials with lower vapor pressures, such as #6 fuel oil and asphalt. The problem lies in taking this measurement. Both products (#6 fuel oil and asphalt) are thick, black, sticky substances. They do not flow easily through the glassware used in the test method, and reading the exact level is extremely problematic.

  In addition, due to the viscosity of #6 fuel oil and asphalt, air or water is often entrained within samples, and both can skew test results. Finally,

[58] ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes technical standards for a wide range of materials, products, systems, and services.

ASTM D2879 is designed to determine the vapor pressure of pure substances. These products are complex mixtures of both light and heavy compounds.

A webinar prepared by the American Institute of Chemical Engineers (AIChE), *Evaluating Methods for Determining the Vapor Pressure of Heavy Refinery Liquids*, provides additional information on the difficulties associated with measuring #6 fuel oil and asphalt vapor pressures.[59]

b. EPA Testing Conducted at Two Maine Facilities

EPA required two petroleum storage facilities in Maine to conduct testing from heated petroleum storage tanks in 2012-2014. Results of initial testing showed no standing loss emissions because the flow rate was below the instrumentation detection level and therefore represented as “zero flow.” EPA required the facilities to build a temporary total enclosure (TTE) over the tank’s vents in order to collect any/all emissions and a fan to pull air past the tank vent at a set rate to create a steady, measurable flow rate that could be used with measured concentrations to determine mass emission rates of specific pollutants.

This approach differed from emissions testing conducted for the purposes of a compliance demonstration, which is conducted under conditions representative of a source’s normal operations, excluding a few specific scenarios. (There are some circumstances where non-representative operation is desirable, such as during trial burns, but those are the exception.)

When product is being added to storage tanks, there is an outflow of vapors from the headspace equal to the volume of the product added. This could potentially be measured using typical EPA reference methods without the use of a TTE, though the duration of such filling activities is limited. When product is not being added or removed, storage tanks are in a “resting” state and very little flow occurs.

During periods when no loading or unloading is occurring, tanks can “breathe.” As an uninsulated resting tank heats up during the day due to absorption of solar energy, the change in temperature can cause some of the stored product to volatilize into the headspace of the tank, creating a slight pressure differential between the tank and ambient air, and causing vapors to be released through the vent or vents on the tank in question. Then, as the sun sets and the previously absorbed heat energy is released, the vapors in the tank above the liquid level cool, causing ambient air to be drawn into the headspace of the tank and diluting the vapors. The cooler temperature can also cause some of the vapors to condense

[59] The webinar is available at https://www.aiche.org/academy/webinars/evaluating-methods-determining-vapor-pressure-heavy-refinery-liquids.

back into liquid form and assimilate back into the main volume of stored product. If a tank has multiple vents, it is possible for ambient air to be drawn in at one vent while vapors are being exhausted at another vent. Throughout this process, the system is trying to reach and maintain a state of equilibrium between liquid and gaseous phases based on the properties of the product, the headspace volume, the surface area of the product exposed to the headspace, pressures, temperatures, solar incidence, etc. Wind movement across the vents can induce drafts, at times, though it would not be as continuous or consistent as artificial flow created by the TTE.

Conditions created by a TTE with a fan inducing a steady vacuum and draft on and across the vents prevents the equilibrium processes described above from happening normally. When evaporation of a liquid occurs in a closed space, molecules of the liquid enter the vapor phase from the liquid phase and vice versa, and a dynamic equilibrium is established between the two phases. At this equilibrium, the rate of evaporation is equal to the rate of condensation. If the liquid is in an open container, the molecules in the vapor phase spread, and some will exit from the container. The required TTE and fan used to pull a vacuum on the tanks during testing potentially pulled gases from the tank that would not have exited the tank without the artificially induced flow. By drawing gaseous components from the tank, the concentration of petroleum molecules in the gaseous phase was lowered, thereby inducing more molecules to move from the liquid surface into the gaseous phase until equilibrium between the two phases was reestablished.[60] By continuously drawing out vapors and preventing the system from reaching equilibrium, it is likely that more of the product became volatilized in the headspace. Continuous exhausting of vapors at the rates created by the fan on the TTE is not "representative" behavior for a petroleum storage tank.

The testing contractor in these specific tests noted that the TTE/fan combination could also have been drawing and exhausting mist/droplets that would otherwise not have exited the tank. During the first portion of sampling, the sample system on the asphalt tank did not include a coalescing filter to remove oil mist/droplets. When a filter was added, there was a noticeable drop in measured VOC concentrations. In the absence of sampling under ambient conditions (no TTE/fan collector), it is impossible to state with certainty that the mist and droplets were not produced by operation of the TTE and associated fan. The tester also noted

[60] https://blog.siplo.lk/2020/05/19/liquid-gas-equilibrium/

that the emissions concentrations were affected by the fan speed: changing the flow rate in the TTE caused the concentrations being measured to also change[61].

c. Current Testing Requirements for Vessel Loading and Switch-Loading

Maine petroleum storage facilities are required to control emissions from vessel loading from non-heated tanks through the use of a vapor collection system to route vapors to a vapor combustion unit (VCU) or vapor recovery unit (VRU), as identified in individual air emission licenses. These vapor control systems are required to be tested to demonstrate compliance with associated emission limits and control efficiency requirements on a frequency specified in each facility's air emission license. A vapor control method is required to control emissions from the loading process whenever gasoline is loaded or whenever a truck is loaded that carried gasoline as its most recent previous load (a procedure known as "switch loading"). The vapor control system must meet a specified standard (VOC emissions not to exceed a specified limit, in milligrams per liter of product loaded), and each facility must periodically test the loading rack vapor control system to demonstrate compliance with their license requirements.

2. Calculating Emissions

Emissions can also be estimated based on calculations using established emission factors. Typically, those factors are based on a large number of physical samples of actual emissions to give a representative average of emissions from a given type of facility/source.

a. AP-42 (new & old)

The EPA's AP-42, *Compilation of Air Pollutant Emissions Factors*, originally published in 1972, is the primary compilation of EPA's emissions factors and process information for more than 200 air pollution source categories. AP-42 emission factors are developed and compiled from source test data, material balance studies, and engineering estimates. Since the original edition, EPA has published supplements and updates to AP-42. EPA recommends AP-42 for use by states to estimate federally reportable emissions for emission units where source-specific testing results are not required or available.

Chapter 7 of AP-42 presents models for estimating air emissions from organic liquid storage tanks, including petroleum storage tanks. Chapter 7 includes

[61] Stratton, Anthony M. (2014, 24 November). Anthony Stratton to refineryfactor@epa.gov November 24, 2014 [Letter]. Comments submitted on behalf of Eastmount Environmental Services, LLC and its clients, in response to EPA request for comments on suggested revisions to AP-42.

emissions estimating methodologies for storage tanks of various types and operating conditions. The methodologies are intended for storage tanks that are properly maintained and in normal working condition. They are not intended to address conditions of deteriorated or otherwise damaged structural components or operating conditions that differ significantly from the scenarios described in the chapter.

Estimation methodologies for routine emissions (standing/breathing and working losses) from both fixed roof tanks and floating roof tanks are included. The equations were developed to estimate average annual losses for storage tanks. Provisions for applying the equations to shorter time periods are addressed but have an associated increase in uncertainty.

The equations are a function of temperatures derived from a theoretical energy transfer model. In order to simplify the calculations, default values were assigned to certain parameters in the energy transfer equations. The accuracy of the resultant equations for any individual tank depends upon how closely that tank fits the assumptions inherent to these default values. The associated uncertainty may be mitigated by using measured values for the temperature of the stored product.

In addition to standing and working losses, AP-42 Chapter 7 also includes methodologies for estimating emissions resulting from the landing of a floating roof, emissions resulting from tank cleaning, emissions from variable vapor space tanks, and emissions from equipment leaks associated with pressure tanks designed as closed systems.

AP-42 Chapter 7 received a significant update on November 20, 2019, as well as minor corrections in March 2020 and June 2020. These changes include updates to increase the accuracy of emissions estimation methodologies and are summarized below.

- The original temperature equations in AP-42 Chapter 7 were derived from American Petroleum Institute Publication Chapter 19.1D, *Documentation File for API Manual of Petroleum Measurement Standards Chapter 19.1 – Evaporative Loss From Fixed Roof Tanks*, First Edition, March 1993. The development of these equations included several approximations and substitutions to simplify the calculations. The equations have been revised as follows to more accurately reflect the theoretical derivations.
    - The default expressions for the average liquid surface temperature (T_{LA}) and average daily vapor temperature range (ΔT_V) are based on a uniform assumption of 0.5 for the tank height-to-diameter ratio (H/D). More general forms of these equations are included in the update with H/D as a variable.

  - The equation for calculating the liquid bulk temperature (T_B) was updated to account for solar radiation striking the tank. The new equation was developed from the same theoretical energy transfer model as the other temperature equations.
  - New equations for T_{LA} were added for floating roof tanks, with separate equations for different types of floating roof decks.
  - A new equation for T_B for floating roof tanks was added for use when measured values for T_B are unavailable.
- When alternative equations are available, language was included to indicate which equation is more accurate and what criteria need to be met for simplified forms of the equations to be acceptable.
- An equation was added for calculating the vapor space temperature (T_V). This was incorporated into the equation for calculation of the stock vapor density (W_v), which was previously approximated using the average liquid surface temperature.
- Guidance was added for estimating emissions from fully insulated tanks. Because minimal heat transfer occurs through the roof and shell of an insulated tank, it is assumed that the liquid surface temperature is equal to the liquid bulk temperature, and that there is no generation of breathing loss from the ambient diurnal temperature cycle. Breathing losses may still be driven by temperature cycles in the heating of liquid stock. Equations are provided to estimate heating-cycle breathing losses.
- Guidance was added for estimating emissions from partially insulated tanks. Temperature equations for more accurate modeling of partially insulated tanks were added, rather than modeling the tanks as non-insulated.
- The procedure for estimating floating roof landing losses was updated to use a more accurate equation for the vapor space expansion factor (K_E). Guidance was also added for estimating emission losses from roof landings of less than 24 hours' duration.
- A section was added for estimating emissions resulting from the cleaning of storage tanks.
- A section was added for estimating emissions resulting from evaporation, of material from the sides of the tank structure, also called flashing.
- An explanation was added for why the routine emissions equations are not suitable for estimating emissions for time periods shorter than one month.

b. TANKS 4.09D

A software program entitled "TANKS 4.09D" is available through the EPA website. It was developed based on the emission estimation procedures presented in a previous version of AP-42 Chapter 7 and can calculate VOC and HAP emission from fixed and floating roof storage tanks. TANKS 4.09D was last updated on October 3, 2005, and as such does not include the most up-to-date calculation methodologies presented in the current version of AP-42 Chapter 7. The TANKS 4.09D program contains known errors and is no longer supported by EPA, but it continues to be made available for historical purposes.

c. Commercially Available Software Products

In addition to TANKS 4.09D, other software packages for calculating emissions from storage tanks are available commercially. Some examples include TankESP produced by BREEZE software; ProMax produced by Bryan Research & Engineering, LLC; and E&P Tanks produced by American Petroleum Institute. These software products may use the methodology from AP-42 Chapter 7, other thermodynamic equations, or a combination to calculate emissions. The scope, functionality, and available support differs significantly in the available commercial software options. The cost of this third-party software ranges from $1,000 to over $10,000 per license depending on the sophistication of the software package and level of support provided by the supplier.

3. Continuous Emission Monitoring System (CEMS)

A continuous emission monitoring system (CEMS) is a combination of equipment used to continuously measure specific pollutants in exhaust gases emitted into the atmosphere. A typical CEMS consists of a sample probe, filter, sample line, gas conditioning system, calibration gas system, and series of gas analyzers which reflect the parameters being monitored. Some commonly used gas analyzers include infrared and ultraviolet adsorption, chemiluminescence, fluorescence, and beta ray absorption. A data acquisition and handling system then receives the signal output from each analyzer to collect and record emissions data. CEMS are required by some federal and state regulations as a means to comply with air emission standards. Facilities use CEMS to continuously collect, record, and report the required emissions data. Typical monitored pollutants include sulfur dioxide, nitrogen oxides, carbon monoxide, carbon dioxide, hydrogen chloride, airborne particulate matter, mercury, VOC, and oxygen. CEMS can also measure air flow, flue gas opacity, and moisture content. For each CEMS, the facility is required to perform periodic performance evaluations of the CEMS equipment, including daily calibration error tests, daily interference tests for flow monitors, and quarterly or annual calibration gas audits (CGA) or relative accuracy test audit (RATA) and bias tests.[62]

CEMS are effective on emissions sources with identifiable and relatively consistent flow, such as stacks from power boilers or emissions exhaust points from manufacturing processes. Emissions from petroleum storage tanks are neither readily

[62] https://web.archive.org/web/20090211082920/http://epa.gov/airmarkets/emissions/continuous-factsheet.html

measurable nor consistent in expected flow rates. For example, the flow rate of breathing losses from heated petroleum storage tanks has not been able to be measured by EPA-required testing at two facilities in Maine due to flow rates being below detection levels of certified and test-method-specified flow meters. Thus, a flow would have to be induced to provide an emissions stream to continuously monitor. This would artificially increase emissions from heated tanks, necessarily resulting in measurement of nonrepresentative emission levels. The flow rates of working losses from heated tanks (during tank filling processes) can be measured, but tank filling events occur relatively infrequently, such that most of the time, the CEMS would sit idle because of the lack of a measurable flow rate.

By design, the gaseous stream collected and routed to odor control equipment recently required for a Maine petroleum storage facility will be a mix of ambient air and vapor emanating from the roof vents of the tanks. During times other than tank filling events, which happen infrequently (one facility reported tank filling events approximately once per month for 12-16 hours of duration), emissions will be from tanks “breathing,” and the concentration is expected to be low. Additionally, the exhaust stream is expected to have a relatively high moisture content. VOC components from residual oil and asphalt will tend to be longer-chained (higher molecular weight) molecules that readily condense with moisture droplets. Such an exhaust stream would require preconditioning to remove the condensate to protect against plugging of a CEMS sensor. With the condensate removed, the CEMS measurements would likely be biased low.

Another consideration would be the ability of a CEMS to accurately quantify the VOC concentration given the wide range of VOC compounds. The response factor of the system for measuring short-chain hydrocarbons would be different than a response factor for long-chained hydrocarbons. CEMS currently in use in the petroleum terminal industry are common for gasoline vapors from gasoline loading racks, are only used on the exhaust of carbon vapor recovery control systems as a yes/no indicator for emission breakthrough of the carbon (to then signal to stop gasoline loading). There are no known examples of CEMS in use at residual oil storage facilities equipped with odor controls in the U.S or Canada.

The Department does not recommend requiring the use of CEMS to determine emissions from petroleum storage tanks. The use of CEMS technology is not technically or economically justified at this time.

4. Leak Detection and Repair Using Forward-Looking Infrared (FLIR) Technology

Leak detection using infrared technology is an effective way to identify and minimize losses to the atmosphere of gaseous emissions at petroleum storage facilities. An infrared camera is a non-contact device that detects infrared energy (heat) and converts it into an electronic signal, which is then processed to produce a thermal image or video. Thermal energy is transmitted in the infrared wavelength (1 to

100 micrometers, or µm). Heat sensed by an infrared camera can be used to identify and evaluate the relative severity of heat-related problems.[63] Infrared technology has multiple uses, including surveillance of living things (such as people or animals), watershed temperature monitoring, detection of energy loss or insulation defects in buildings, target acquisition and tracking in military applications, piloting of aircraft in low visibility conditions, locating living things and sources of ignition in firefighting operations, detecting heat in faulty electrical joints, searching for drug labs at night, monitoring active volcanoes, and detecting leaks of natural gas and other gases.

The term FLIR, a US military acronym that officially stands for “forward looking infrared radar,” is generally considered to stand for “forward looking infrared” in common usage. This refers to the technology used to create an infrared image of a scene without having to “scan” the scene with a moving sensor. It is also the name of the largest manufacturer of thermal imaging cameras (FLIR Systems Inc.).

FLIR technology can be coupled with optical gas imaging technology to detect and visualize methane, sulfur hexafluoride, and many other industrial gases, which, when detected, appear as plumes of “smoke” in a thermal image or video. In comparison, the Toxic Vapor Analyzer, or sniffer, historically used to detect the presence of gaseous substances, can only detect gas by placing the probe directly on the equipment component or in the suspected stream of emissions, inspecting one point at a time.[64] More and more, FLIR technology is being used in the petroleum industry to conduct routine monitoring for leaks and other sources of emissions to ambient air, enabling faster inspections and more effective leak source identification.

C. Air Quality Monitoring

1. Mobile Devices

Many mobile or portable air quality monitoring devices are available from a variety of commercial sources to measure concentrations of pollutants in the ambient air. These devices represent air quality conditions only at the location where samples are collected. These vary widely in the types of air pollutants they measure, the range of concentrations they are capable of detecting, measurement methods used, methods used for management of data readings, and power sources. Real-time data output is also a typical feature. Cost typically ranges from a few hundred dollars to a few thousand dollars. Some vendors even offer a lease option. While some of the more readily available and widely used devices are those that measure particulate matter

[63] *English contemporary dictionary. 2014.*
[64] https://www.flir.ca/discover/instruments/gas-detection/insights-from-the-field-how-ogi-cameras-improve-gas-leak-detection-and-environmental-health/

(PM) of different size fractions (e.g., PurpleAir and Clarity sensors), this report only focuses on devices capable of measuring gases such as VOC and polycyclic aromatic hydrocarbons (PAHs), the primary category of HAP emitted by petroleum storage facilities.

The majority of air quality sensor development has been focused on air pollutants for which there are National Ambient Air Quality Standards (NAAQS), such as ozone, carbon monoxide, sulfur dioxide, and nitrogen dioxide. Unfortunately, there are far fewer sensor devices available for gaseous HAP and VOC. Examples of VOC devices include the following:

- UniTech
- ToxiRae
- EPA VOC
- Air Quality Egg

These devices, like most VOC sensors, measure total VOC using a photoionization detection method with a detection limit in the range of 5-20 parts per billion. Measurement of specific VOC, HAP, or PAH require physical sample collection and off-site laboratory analysis.

While portable VOC sensor devices have the advantage of being relatively low-cost, their usefulness is limited due to their inability to measure specific VOC that are typically associated with petroleum storage tanks, as well as their detection thresholds being too high to measure ambient concentrations that can have health impacts. Therefore, using a canister sampling device for VOC or a sorbent tube sampling device for PAHs, coupled with a laboratory analysis of the samples, is both a mobile and more refined approach for measuring the air pollutants of concern in monitoring tank emissions. While the costs of sampling hardware are relatively inexpensive, the need for accompanying laboratory sample analyses (with its associated quality assurance and quality control protocols) adds recurring costs and leads to a delay in obtaining the final results. However, canisters and sorbent tube methods are viable options for municipalities, as demonstrated by Phases 1 and 3 of the South Portland/Portland (SOPO/Po) VOC Air Quality Project (https://www.maine.gov/dep/air/monitoring/spo-voc-monitor.html).

2. Fenceline Monitoring: EPA Method 325

No requirements for fenceline monitoring exist within federal rules for petroleum storage facilities. However, petroleum refineries are required by the EPA[65] to continuously monitor for benzene and VOC from specific emission units within facilities and around facility perimeters using EPA Method 325, *Volatile Organic Compounds from Fugitive and Area Sources*. Method 325 consists of the following two parts:

- Method 325A, *Sampler Deployment and VOC Sample Collection*; and
- Method 325B, *Sampler Preparation and Analysis***.**

Method 325A prescribes the methodology and equipment for collection of VOC at or inside a facility property boundary or from fugitive and area emission sources using passive (diffusive) tube samplers specifically tailored to adsorb targeted compounds. This method requires deployment of passive sampling tubes on a monitoring perimeter encompassing all known emission sources at a facility and concurrent collection of local meteorological data. The concentration of airborne VOC collected at or near these potential sources may then be determined using Method 325B. Method 325B describes preparation of sampling tubes, shipment and storage of exposed sampling tubes, and analysis of sampling tubes collected. Method 325B directs thermal desorption/gas chromatography (TD/GC) analysis of the collected samples. The preferred GC detector for this method is a mass spectrometer (MS), but flame ionization detectors (FID) may also be used. Other conventional GC detectors such as electron capture (ECD), photoionization (PID), or flame photometric (FPD) may also be used if they are selective and sensitive to the target compounds and if they meet the method performance criteria provided in this method.

Method 325 is not suitable for particulate pollutants (i.e., fumes, aerosols, and dusts), for compounds too reactive for conventional GC analysis, or for VOC that are more volatile than propane.

A diffusive passive sampler collects VOC from air for a measured time period at a rate proportional to the concentration of vapor in the air at that location. The duration of each sampling period is normally 14 days. Thus, this method may be applied to screening average airborne VOC concentrations at facility property boundaries or monitoring perimeters over an extended period of time using multiple sampling periods (e.g., 26 x 14-day sampling periods). At the end of each sampling period, the

[65] 40 C.F.R. Part 63, Subpart CC, *National Emission Standards for Hazardous Air Pollutants from Petroleum Refineries*, and Subpart UUU, *National Emission Standards for Hazardous Air Pollutants for Petroleum Refineries: Catalytic Cracking Units, Catalytic Reforming Units, and Sulfur Recovery Units*; and 40 C.F.R. Part 60, Subpart Ja, *Standards of Performance for Petroleum Refineries for Which Construction, Reconstruction, or Modification Commenced After May 14, 2007*; collectively referred to as the Refinery Sector Rule

passive samples are collected, sealed, and shipped to a laboratory for analysis of target VOC by thermal desorption gas chromatography, as described in Method 325B.

Method 325 requires the additional collection of local meteorological data (wind speed and direction, temperature, and barometric pressure). Although local meteorology is a component of this method, non-regulatory applications of this method may use regional meteorological data, but the use of such regional data introduces risk that the results may not identify the precise source of emissions.

The rate of sampling is specific to each compound and depends on the diffusion constants of that VOC and the sampler dimensions, packing, and characteristics as determined by prior calibration in a standard atmosphere. In the sampling time period, gaseous VOC target compounds in ambient air migrate through a constant diffusion barrier (e.g., an air gap of fixed dimensions) at the sampling end of the sampling tube and adsorb onto the sorbent.

At the lab analyzing the samples, heat and a flow of inert carrier gas are then used to extract (desorb) the retained VOC back from the sampling end of the tube and transport/transfer them to a gas chromatograph (GC) equipped with a chromatographic column to separate the VOC and a detector to determine the quantity of target VOC. This method requires the use of field blanks to ensure sample integrity associated with shipment, collection, and storage of the passive samples. It also requires the use of field duplicates to validate the sampling process.

The EPA method includes cautions against general interferences which include possible influencing obstructions to air flow such as trees, walls, buildings, bodies of water, and hills at the monitoring site. The method also includes cautions of background pollution interference, including from nearby or upwind sources of target emissions outside the facility being tested, such as neighboring industrial facilities, transportation facilities (e.g., nearby airports, train/rail traffic, highways), fueling operations, combustion sources, short-term transient sources, and residential sources. Also, because passive samplers continuously sample ambient air, changes in wind direction can cause variation in the level of background concentrations from interfering sources during the monitoring period.

Indicators as to why this monitoring method may not be compatible with monitoring at bulk petroleum storage facilities in Maine include the following:

- The normal working range of sorbent packing for field sampling is 0 – 40 °C (32 – 104 °F). Maine's ambient temperatures, specifically during the winter season, go below the lower temperature boundary for the sorbent.
- In locating meteorological instruments, the method advises the following: "If possible, locate wind instruments at a distance away from nearby structures that is equal to at least 10 times the height of the structure." Within the South Portland

area with petroleum storage facilities, for example, some facilities are within closer proximity to one another and to other structures than 10 times the height of a tank (tank height is approximately 50 feet).

Temperature sensors must be located at a distance away from any nearby structures that is equal to at least four times the height of the structure, and at the same time, temperature sensors must be located at least 30 meters (98 feet) from large paved areas.

- Between 12 and 24 monitors are required around the perimeter of each petroleum refinery, based on the size of the facility. Each petroleum refinery covers hundreds of acres. Maine petroleum storage facilities cover areas far smaller than a petroleum refinery.

3. Fenceline Monitoring: Other Methods

There are several air quality jurisdictions in California with fenceline monitoring rules in place: Bay Area Air Quality Management District (BAAQMD), South Coast Air Quality Management District (SCAQMD), San Joaquin Valley Air Pollution Control District (SJVAPCD), Santa Barbara County Air Pollution Control District (SBAPCD), and the California Air Board. These jurisdictions generally require refinery fenceline continuous monitoring, with real-time reporting, for many pollutants including but not limited to total VOC, sulfur dioxide, nitrogen oxides, acrolein, styrene, formaldehyde, benzene, cadmium, manganese, nickel, arsenic, beryllium, hexavalent chromium, diethanolamine, naphthalene, and polycyclic aromatic hydrocarbons (PAHs).

These regulations require a wide variety of instruments to meet the rules, including the following:[66]

- Point monitors (mostly traditional)
  - $PM_{2.5}$, PM_{10}, black carbon, ultrafine PM (BAMs[67], aethalometers, etc.)
  - Metals (XRF[68], filters)
  - Gases (AutoGCs[69], PIDs[70], cavity ringdown, chemiluminescent)
- Open-path monitors
  - Depending on pollutant (UV-DOAS, FTIR, TDLAS, QCL[71])

[66] Presentation by Clinton P. MacDonald, of Sonoma Technology, for the Air & Waste Management Association 113th Annual Conference & Exhibition, July 2, 2020
[67] Beta attenuation monitor
[68] X-ray fluorescence
[69] Automatic gas chromatograph
[70] Photoionization detector
[71] Quantum cascade laser

  - Mostly gaseous compounds at reasonable MDL[72]
- Low-cost sensors
  - Potential for some gases (e.g., total VOC, NO_x)
  - Evolving technology

Challenges with implementing this type of monitoring system also include the ability to identify and isolate emissions from specific sources, identifying which species to measure for, instrumentation options, data interpretation, and data availability and explanation. Experience at facilities currently complying with these requirements identify additional challenges, including public not believing non-detect results and lack of thorough QA/QC applied to real-time data at the time of publication, which increases the risk of false alarms. In addition, a scientific approach to monitor placement can be inappropriately influenced by the public and political processes. Furthermore, the infrastructure for this type of monitoring is very expensive.

4. Assisting Municipalities with Monitoring

Maine DEP's Bureau of Air Quality does not have a formalized program for providing assistance to Maine municipalities to monitor ambient air quality. Any past assistance has been provided on an ad hoc basis, as Department resources have allowed, and the Department intends to continue with that approach. The EPA has established air sensor loan programs through various collaborations with community groups, schools, libraries, and others to enable the public to learn about air quality in their communities. These programs are provided to bring new air sensor technology advances to the public for educational purposes. Sensors available through these loan programs are not intended for regulatory use, as those used for regulatory purposes are subject to stringent calibration protocols in order to assure accurate and consistent data. Such calibration is not an available component of the EPA's loan programs.

EPA Region 1, headquartered in Boston, MA (serving Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, and ten Tribal Nations) participates in the agency's Regional Air Sensor Loan Program. The equipment that is available for loan is the ARISense device. It measures carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), ozone (O_3), carbon dioxide (CO_2), particulate matter (PM), solar intensity, noise, wind speed, and wind direction.

The following URLs contain more specific information and details about this program:
https://www.epa.gov/air-sensor-toolbox
https://www.citizenscience.gov/air-sensor-toolbox/

[72] Minimum detection limit

VI. Conclusions and Recommendations

A. Controlling VOC Emissions

1. Gasoline

The storage and distribution of gasoline is already highly regulated at both state and federal levels. Additional controls beyond those already required would likely not result in any meaningful emissions reductions.

2. Distillate Fuel

Distillate products are often stored in fixed roof tanks. While retrofitting existing fixed roof distillate fuel tanks with a floating roof is unlikely to cause significant emission reductions, the Department has determined as a result of this study that new distillate storage tanks greater than 39,000 gallons should be equipped with a floating roof.

Loading distillate fuel into a truck for which the most recent previous load was gasoline is known as switch-loading. At facilities which are required to have an air emission license, switch-loading is typically prohibited unless vapors displaced during cargo tank loading are sent to a VOC collection and control system. The Department will propose to the Board of Environmental Protection revisions to *Bulk Terminal Petroleum Liquid Transfer Requirement*, 06-096 C.M.R. ch. 112, that prohibit switch-loading at any facility subject to that chapter unless equipped with a VOC collection and control system.

3. Residual Oil and Asphalt

The Department's investigation into the types of add-on control equipment currently being used to control emissions from heated, fixed-roof residual oil and asphalt storage tanks revealed that the majority of tanks of this type being operated in the United States do not utilize any type of add-on control equipment to reduce emissions. There are a limited number of tanks of this type that do utilize add-on control equipment for various other reasons. Some facilities have either been required to install or have voluntarily installed a combination of mist elimination and carbon bed adsorption equipment or in some cases thermal oxidation equipment to reduce emissions (some for odor reduction purposes and others for purposes of ensuring facility-wide VOC emissions remain below major source threshold levels).

Thermal oxidation systems are expected to be very effective in reducing VOC, HAP, and odor-causing compounds from tanks of this type; however, thermal oxidation systems can be very expensive to install and operate.

Carbon adsorbers may be designed to reduce emissions of both VOC and odors from heated, fixed roof storage tanks. However, if carbon adsorbers are not carefully monitored and maintained, they risk increasing emissions instead of reducing them. Therefore, carbon adsorbers should only be considered for tanks at facilities which have an air emission license where monitoring and recordkeeping requirements can be specified and compliance determined through regular inspections. Additionally, the overall effectiveness and longevity on emissions reductions from heated residual oil and asphalt tanks is not known.

Therefore, the Department will evaluate the operational effectiveness of the mist elimination and carbon bed adsorption equipment currently planned to be installed to determine whether this type of equipment should be required on other heated, fixed-roof residual oil and asphalt storage tanks located at bulk storage facilities in Maine in the future.

To accurately evaluate this equipment, characteristics of the material stored in each tank must be identified. Therefore, the Department will require recordkeeping of the amount and type of any material added to heated petroleum storage tanks at licensed facilities, including any additives. The authority for this recordkeeping requirement already exists in the Bureau of Air Quality's licensing regulations. This requirement has been included in recently issued air emission licenses and will be included as appropriate in the licenses of other petroleum storage facilities state-wide.

The Department will also require that all heated, fixed roof petroleum storage tanks be fully insulated and the temperature of the stored material monitored to minimize temperature fluctuations which lead to breathing losses. This authority already exists in the Bureau of Air Quality's licensing regulations and is already being implemented.

B. Controlling Odor

The characterization, measurement, and quantification of odors from petroleum storage facilities is complex. There is limited information on the use and effectiveness of existing odor control technologies. Therefore, the recommendations of this report are focused on additional evaluation and data gathering.

Maine will soon have two facilities with operational odor control technologies, and with their debut will come the opportunity to measure their effectiveness. Data showing emissions from the subject tanks and how those emissions are affected by mist elimination and carbon adsorbers will provide important information to inform possible future requirements. The Department will evaluate data from these facilities including the following:

- Emissions prior to controls;

- Emissions post-controls;
- Variations in emissions, seasonally and operationally; and
- Observations in the community of changes in perceptible odors, including both odor intensity and character.

The first three bullets above could be evaluated based on measurable VOC emissions and changes, since VOC are more readily measured and could be used as a surrogate for odorous compounds. When reviewing the use of these controls in practice, the Department will also identify unintended consequences of such controls, either positive or negative, and evaluate such consequences to more fully inform future requirements.

The fourth bullet, as described in the paragraphs above, is a subjective measure and would be best to document for at least a year, since seasonal variations are expected.

Regulatory standards for odor controls would be best approached after conducting studies and documenting the effectiveness of various control options.

C. Determining Emissions

1. Gasoline and Distillate Storage Tanks

   Emissions calculations as described in the most current version of AP-42 are considered the most accurate method for estimating emissions from unheated petroleum storage tanks. Although EPA's TANKS 4.09D will likely still give reasonable results for unheated tanks when compared to the most current AP-42 methodology, that program is no longer updated or supported by EPA, and the Department will not accept its use for compliance with annual emission reporting requirements.

2. Heated, Fixed-Roof Residual Oil and Asphalt Storage Tanks

   The Department will establish requirements in air emission licenses for those facilities installing odor control equipment on heated petroleum storage tanks due to consent agreements with EPA to require emissions testing. The Department will ensure testing is performed both upstream and downstream of the odor control equipment in order to determine the effectiveness of the equipment on reducing emissions (VOC, HAP, and those pollutants expected to significantly contribute to the types of odors being experienced by the community).

   Once completed, this evaluation will be used by the Department to inform decisions about whether this type of equipment should be required on other heated petroleum storage tanks located in Maine. This evaluation will also be used by the Department to determine any operational and maintenance procedures that should be required at facilities operating this type of odor control equipment.

The Department will use existing regulatory authority to require bulk petroleum storage facilities to conduct emissions testing for new or modified heated petroleum storage tanks greater than 39,000 gallons to establish site-specific emission factors that may be used for annual emission reporting and determining compliance with licensed emission limits. The Department will continue to accept use of the most current version of AP-42 emission estimating methods where site-specific testing is not required.

3. Product Loading

Air emission licenses already require control equipment associated with gasoline loading racks to be tested on a regular basis. Additionally, some testing has been performed on the top loading of heated products. The Department will require the use of on-site emissions test data for determining actual emissions whenever such data is available. For the loading of products without representative on-site emissions test data available, the Department will accept the use of the most current version of AP-42 emission estimating methods to determine emissions.

4. Emissions Calculations Software

The Department will explore federal funding opportunities to purchase commercially available software capable of calculating emissions in accordance with the most current version of AP-42.

5. Stack Testing Methods

The Department recommends and supports the development of an EPA standard test method, developed in accordance with EPA criteria for developing test methods as promulgated in the Federal Register, to quantify emissions from tanks with passive vents. Results from application of this method should then be used to update AP-42.

D. Monitoring

1. Ambient Air Monitoring Efforts

The Department supports continuing the ambient air monitoring study, which began in 2019 in coordination with the Cities of South Portland and Portland. This study continues to provide valuable information regarding the air quality within these communities and is being used by the Department and the Maine Center for Disease Control (Maine CDC) to inform the communities. The Department is exploring with EPA the option to use HEM-3 modeling to confirm or otherwise inform ambient air monitoring stations are sited at the most appropriate locations for the purposes of the study.

2. Fenceline Monitoring

   The Department does not recommend fenceline monitoring at this time. Fenceline monitoring is most commonly used around the perimeter of large facilities, such as petroleum refineries, with few or no other emissions sources nearby. Given the proximity of petroleum storage facilities in South Portland to one another and to other significant emissions sources such as highways, railways, marine vessels, and even local traffic and home heating combustion sources, as well as expected emissions release points at tank-top levels, and considering typical air movement and dispersion characteristics, fenceline monitoring for any given facility is not expected to provide much useful data. Emissions from any given source may not impact ground level within the fenceline before being mingled with emissions from other nearby sources, so pollutants detected on fenceline monitors in an area with several potential emissions sources would not necessarily be directly attributable to the facility at whose fences the monitors are located.

3. Continuous Emissions Monitoring Systems

   The Department does not recommend the use of continuous emission monitoring systems (CEMS) to determine emissions from petroleum storage tanks. CEMS are effective on emissions sources with identifiable and relatively consistent flow, such as stacks from power boilers or emissions exhaust points from manufacturing processes. The flow rate of breathing losses from heated petroleum storage tanks has not been able to be measured by EPA-required testing at two facilities in Maine due to flow rates being below detection levels of certified and test-method-specified flow meters. Thus, a flow would have to be induced to provide an emissions stream to continuously monitor. This would artificially increase emissions from heated tanks, necessarily resulting in nonrepresentative levels.

   The Department recommends that forward-looking infrared (FLIR) technology be used at bulk petroleum storage facilities to monitor for vapor leaks around the storage tanks, piping, and fittings associated with their facilities and to inform appropriate equipment repairs. This monitoring should be conducted at least on a monthly basis, and documentation of FLIR findings and associated repairs, as appropriate, be made available to the Department upon request. The Department will propose to the Board of Environmental Protection revisions to *Petroleum Liquid Storage Vapor Control,* 06-096 C.M.R. ch. 111, to include this requirement in licenses with petroleum storage tanks of capacity greater than 39,000 gallons.

E. Summary

The Department has sufficient authority through Maine law and EPA delegation to incorporate all necessary and appropriate requirements into the Department's air emission regulations and air emission licenses, including emission controls, compliance monitoring, and recordkeeping requirements. Based on this analysis, the Department will implement the following measures:

Emission Controls

- New distillate storage tanks with capacity greater than 39,000 gallons will be equipped with a floating roof.
- The Department will propose to the Board of Environmental Protection revisions to *Bulk Terminal Petroleum Liquid Transfer Requirement,* 06-096 C.M.R. ch. 112, to prohibit switch-loading at facilities unless equipped with a VOC collection and control system.
- All heated, fixed roof petroleum storage tanks must be fully insulated and the temperature of the stored material monitored to minimize temperature fluctuations which lead to breathing losses.
- The Department will evaluate the effectiveness of mist eliminators and carbon adsorption equipment, required by EPA consent decrees to control odors from heated tanks at certain Maine terminals, to reduce VOC emissions. If this control technology is proven effective as Best Practical Treatment to control VOC emissions from heated petroleum storage tanks, such technology will be required for all heated tanks in Maine.

Determining Emissions

- The Department will require bulk petroleum storage facilities to conduct emissions testing for new or modified heated petroleum storage tanks greater than 39,000 gallons to establish site-specific emission factors to be used for annual emission reporting and determining compliance with licensed emission limits.
- The Department will require the use of on-site emissions test data for determining actual emissions whenever such data is available. For emissions from facility processes with no available and representative on-site emissions test data, the Department will continue to allow the use of the most current version of AP-42 emission estimating methods to determine emissions.

Monitoring

- The Department will continue to support the ambient air monitoring studies that began in 2019 in coordination with the Cities of South Portland and Portland.

- The Department will propose to the Board of Environmental Protection revisions to *Petroleum Liquid Storage Vapor Control*, 06-096 C.M.R. ch. 111, to require monthly leak detection and repair at all licensed bulk petroleum storage facilities with any petroleum storage tanks of capacity greater than 39,000 gallons. FLIR technology will be required to be used at each bulk petroleum storage facility to monitor for vapor leaks around the storage tanks, piping, and fittings associated with the facilities and to inform appropriate equipment repairs.

In closing, these measures provide a technically sound approach to further reducing VOC and HAP emissions from petroleum storage tanks and facilities in Maine and should provide meaningful reductions in nuisance odors. The Department is also committing to continue its collaborative approach to community scale air quality monitoring in South Portland, Portland and other communities as our resources allow.

Appendix A

Maine Bulk Petroleum Storage Facilities

Following is a list of bulk petroleum storage facilities located in Maine which currently have an Air Emission License. Details on the petroleum storage tanks at each facility and products stored are shown on following pages.

License #	Name	Location
A-97	Sprague Operating Resources LLC	Trundy Road, Searsport
A-161	Penobscot Bay Terminals, Inc.	93 River Road, Bucksport
A-179	Sprague Operating Resources LLC	59 Main Street, South Portland
A-197	Portland Pipe Line Corporation	30 Hill Street, South Portland
A-202	Buckeye Terminals, LLC	730 Lower Main Street, Bangor
A-282	South Portland Terminal LLC	170 Lincoln Street, South Portland
A-390	Gulf Oil Limited Partnership	175 Front Street, South Portland
A-413	Irving Oil Terminals Inc.	52 Station Road, Searsport
A-432	Global Companies LLC	1 Clark Road, South Portland
A-460	Citgo Petroleum Corporation	102 Mechanic Street, South Portland
A-542	Cold Brook Energy, Inc.	809 Main Road North, Hampden

(A-97) Sprague Operating Resources LLC
Trundy Road, Searsport

Tank Number	Capacity (gallons)	Product Stored	Roof Type
1	3,927,756	#6 Fuel Oil	Fixed
2	3,949,890	Asphalt	Fixed
3	6,023,598	Distillate Fuel	Fixed
11	27,848	Distillate Fuel	Fixed
12	27,848	Distillate Fuel	Fixed
101	579,894	Distillate Fuel	Internal Floating
102	2,792,076	Distillate Fuel	Internal Floating
103	4,362,624	Distillate Fuel	Internal Floating
104	4,362,624	Distillate Fuel	Internal Floating
105	5,007,576	Distillate Fuel	Fixed
107	2,014,866	Distillate Fuel	Internal Floating
108	4,362,624	Distillate Fuel	Internal Floating
109	4,362,624	Distillate Fuel	Internal Floating

(A-161) Penobscot Bay Terminals, Inc.
93 River Road, Bucksport

Tank Number	Capacity (gallons)	Product Stored	Roof Type
1	6,200,000	Distillate Fuel	Fixed
2	5,000,000	Distillate Fuel	Fixed
3	2,300,000	Jet Fuel	Internal Floating
4	4,000,000	Distillate Fuel	Internal Floating
5	2,300,000	Jet Fuel	Internal Floating
6	6,200,000	Distillate Fuel	Fixed
7	6,200,000	Distillate Fuel	Fixed

(A-179) Sprague Operating Resources LLC
59 Main Street, South Portland

Tank Number	Capacity (gallons)	Product Stored	Roof Type
3	3,250,296	*See Note a*	Fixed
4	1,320,522	Distillate Fuel	Internal Floating
5	1,337,448	*See Note a*	Internal Floating
7	3,800,370	#6 Fuel Oil	Fixed
13	3,226,398	Distillate Fuel	Fixed
14	4,391,394	Distillate Fuel	Fixed
28	1,715,070	Aviation gasoline	Internal Floating
31	126,000	*See Note a*	Fixed
33	126,000	*See Note a*	Fixed
40	1,281,000	*See Note a*	Fixed
42	6,232,548	*See Note a*	Fixed
101	1,236,438	Distillate Fuel	Internal Floating
103	585,480	*See Note a*	Fixed
104	1,572,270	Distillate Fuel	Internal Floating
105	3,757,488	Distillate Fuel	Fixed
111	2,097,732	Distillate Fuel	Internal Floating
112	2,458,218	Distillate Fuel	Internal Floating
113	2,507,316	Distillate Fuel	Internal Floating
114	2,508,492	Distillate Fuel	Internal Floating
118	3,876,180	*See Note a*	Fixed
201	590,604	Asphalt	Fixed
202	592,242	Asphalt	Fixed
203	592,200	*See Note a*	Fixed
204	16,800	*See Note a*	Fixed
205	16,800	*See Note a*	Fixed
206	193,200	*See Note a*	Fixed
207	1,502,256	*See Note a*	Fixed
208	4,553,766	Asphalt	Fixed
209	3,108,798	Asphalt	Fixed
210	17,136	Distillate Fuel	(Horizontal Tank)
211	17,262	Distillate Fuel	(Horizontal Tank)
212	96,600	*See Note a*	Fixed
215	1,034,460	Asphalt	Fixed
229	18,690	Emulsion	Fixed

[a] These tanks are not currently in use but are being maintained for potential future use.

(A-197) Portland Pipe Line Corporation

30 Hill Street, South Portland

Tank Number	Capacity (gallons)	Product Stored	Roof Type
1	5,796,000	Crude Oil	External Floating
2	5,796,000	Crude Oil	External Floating
3	6,300,000	Crude Oil	External Floating
4	6,300,000	Crude Oil	External Floating
5	6,300,000	Crude Oil	External Floating
6	6,300,000	Crude Oil	External Floating
8	5,670,000	Crude Oil	External Floating
9	5,670,000	Crude Oil	External Floating
10	5,880,000	Crude Oil	External Floating
11	5,880,000	Crude Oil	External Floating
12	5,880,000	Crude Oil	External Floating
13	5,880,000	Crude Oil	External Floating
18	11,256,000	Crude Oil	External Floating
19	6,300,000	Crude Oil	External Floating
20	6,300,000	Crude Oil	External Floating
21	6,300,000	Crude Oil	External Floating
22	6,300,000	Crude Oil	External Floating
23	6,300,000	Crude Oil	External Floating
24	6,300,000	Crude Oil	External Floating
25	6,300,000	Crude Oil	External Floating
26	11,256,000	Crude Oil	External Floating
27	11,256,000	Crude Oil	External Floating
28	11,256,000	Crude Oil	External Floating

(A-202) Buckeye Terminals, LLC
730 Lower Main Street, Bangor

Tank Number	Capacity (gallons)	Product Stored	Roof Type
1	424,454	Distillate Fuel	Fixed
2	635,418	Distillate Fuel	Fixed
6	253,456	Distillate Fuel	Fixed
8	1,027,804	Distillate Fuel	Fixed
9	478,380	Gasoline, Ethanol, Distillate Fuel	Internal Floating
10	373,669	Distillate Fuel	Fixed
11	1,061,298	Gasoline, Ethanol, Distillate Fuel	Internal Floating
16	347,256	Gasoline, Ethanol, Distillate Fuel	Internal Floating
18	183,498	Gasoline, Ethanol, Distillate Fuel	Internal Floating
19	253,429	Distillate Fuel	Fixed
20	967,050	Gasoline, Ethanol, Distillate Fuel	Internal Floating

(A-282) South Portland Terminal LLC
170 Lincoln Street, South Portland

Tank Number	Capacity (gallons)	Product Stored	Roof Type
28	2,204,328	Gasoline, Ethanol, Distillate Fuel	Internal Floating
29	2,228,982	Gasoline, Ethanol, Distillate Fuel	Internal Floating
37	2,674,308	Gasoline, Ethanol, Distillate Fuel	Internal Floating
38	2,675,484	Gasoline, Ethanol, Distillate Fuel	Internal Floating
39	310,548	Gasoline, Ethanol, Distillate Fuel	Internal Floating
40	310,548	Gasoline, Ethanol, Distillate Fuel	Internal Floating
41	310,716	Gasoline, Ethanol, Distillate Fuel	Internal Floating
42	310,338	Gasoline, Ethanol, Distillate Fuel	Internal Floating
43	2,723,784	Gasoline, Ethanol, Distillate Fuel	Internal Floating
44	4,263,630	Gasoline, Ethanol, Distillate Fuel	Internal Floating
30	3,944,766	Gasoline, Ethanol, Distillate Fuel	Internal Floating
32	3,945,102	Distillate Fuel	Fixed
33	2,526,552	Distillate Fuel	Fixed

(A-390) Gulf Oil Limited Partnership
175 Front Street, South Portland

Tank Number	Capacity (gallons)	Product Stored	Roof Type
D1	4,003,566	Gasoline, Distillate Fuel	Internal Floating
D2	3,995,040	Distillate Fuel, Residual Fuel	Fixed
D3	3,828,552	Gasoline, Distillate Fuel	Internal Floating
D4	2,205,042	Distillate Fuel, Residual Fuel	Fixed
D5	3,983,490	Distillate Fuel, Residual Fuel	Fixed
D6	3,992,268	Distillate Fuel, Residual Fuel	Fixed
D7	3,247,062	Gasoline, Distillate Fuel	Internal Floating
D8	5,985,840	Gasoline, Distillate Fuel	Internal Floating
D9	767,466	Gasoline, Distillate Fuel	Internal Floating

(A-413) Irving Oil Terminals Inc.
52 Station Road, Searsport

Tank Number	Capacity (gallons)	Product Stored	Roof Type
1	7,350,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
2	7,350,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
3	3.360,000	Distillate Fuel	Fixed
4	7,350,000	Asphalt, Residual Fuel, Distillate Fuel	Fixed
5	3,360,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
6	5,250,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
7	5,670,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
8	5,670,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
9	4.620,000	Distillate Fuel	Fixed
10	2,100,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
11	1,680,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
12	756,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
13	2,100,000	Distillate Fuel	Fixed
16	168,000	Biofuel, Distillate Fuel	Fixed

(A-432) Global Companies LLC
1 Clark Road, South Portland

Tank Number	Capacity (gallons)	Product Stored	Roof Type
1	2,300,000	#6 Fuel Oil	Fixed
2	2,300,000	#6 Fuel Oil	Fixed
3	2,300,000	#6 Fuel Oil, Asphalt	Fixed
4	1,500,000	Distillate Fuel	Fixed
5	2,300,000	Distillate Fuel	Fixed
6	2,300,000	Distillate Fuel	Fixed
7	2,300,000	Distillate Fuel	Fixed
8	1,550,000	Distillate Fuel	External Floating
9	3,360,000	Asphalt	Fixed
14	410,000	Distillate Fuel	External Floating
15	410,000	Distillate Fuel	External Floating
16	6,800,000	Distillate Fuel	Fixed

(A-460) Citgo Petroleum Corporation
102 Mechanic Street, South Portland

Tank Number	Capacity (gallons)	Product Stored	Roof Type
1	2,800,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
2	4,600,000	Distillate Fuel	Fixed
3	3,800,000	Gasoline, Ethanol	Internal Floating
4	3,800,000	Gasoline, Ethanol	Internal Floating
5	1,300,000	Distillate Fuel	Fixed
6	1,400,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
7	4,200,000	Gasoline, Ethanol, Distillate Fuel	Internal Floating
8	4,200,000	Distillate Fuel	Fixed
9	2,500,000	Gasoline, Ethanol	Internal Floating
10	2,700,000	Gasoline, Ethanol	Internal Floating

(A-542) Cold Brook Energy, Inc.
809 Main Road North, Hampden

Tank Number	Capacity (gallons)	Product Stored	Roof Type
9	1,600,000	Gasoline	Internal Floating
35	420,000	Distillate Fuel	Fixed
44	1,325,000	Distillate Fuel	Internal Floating
66	756,000	Gasoline, Ethanol	Internal Floating
89	240,000	Distillate Fuel	Fixed
90	250,000	Gasoline, Ethanol	Internal Floating
91	252,000	Distillate Fuel	Fixed
92	504,000	Distillate Fuel	Fixed
93	492,000	Distillate Fuel	Fixed