Control of Atmospheric Emissions From Petroleum Storage Tanks

Informative Report No. 2
TI-3 Petroleum Committee
Air Pollution Control Association

Informative Report No. 2, prepared by the TI-3 Petroleum Committee of the Air Pollution Control Association, deals with the control of hydrocarbon vapor emissions from petroleum storage tanks. The report presents the theory of evaporation loss from liquids, describes emission control equipment and its maintenance, and outlines techniques used to estimate the magnitude of and to reduce emissions.

Informative Report No. 2 of the TI-3 Petroleum Committee was first submitted to APCA's Steering Committee and Technical Council on May 6, 1968. It was processed in accordance with the 14 step procedure outlined in the March 1963 *Journal* and was finally approved by APCA's Board of Directors on March 1, 1970. In accordance with the objectives of the Association as they appear in Article XV, Section 4 of the By-Laws, each technical coordinating committee has the task of reviewing and amending its studies as often as necessary in the light of technological changes.

In accordance with procedures adopted by the APCA Technical Council and the Board of Directors, it is now published as representing "the best thinking of the Association."

This study by the Air Pollution Control Association's TI-3 Committee tells why and how hydrocarbon vapors escape from tanks in which petroleum and its products are stored and discusses means used to estimate the magnitude of, and the control of, such emissions.

The report does *not* attempt to distinguish between the hydrocarbon emissions that are relatively unreactive, such as paraffins and naphthenes, and are therefore not smog precursors, and the relatively reactive emissions, such as olefins and substituted aromatics, that may react with nitrogen oxides in the presence of sunlight, to form ozone and other oxidation products which contribute to Los Angeles-type photochemical smog.

Facts presented herein were selected from chemical texts, engineering reports, and oil industry publications. A list of reference sources concludes this report.

It is hoped that this report will aid control officers and others in making objective assessments when judging the need for, or the establishment of, abatement procedures in their communities.

THEORY OF EVAPORATION LOSS FROM TANKS

Evaporation is a natural process whereby a volatile liquid is converted into a vapor. The driving force that causes vaporization is the vapor pressure of the liquid.

The liquid may be unconfined or enclosed in a container, such as a tank. A liquid confined in a tank may or may not have a vapor space above the liquid. Where there is such a vapor space, the vapor pressure will cause molecules in the liquid to vaporize and disperse throughout the vapor space. At the same time, some molecules in the vapor space will return to the liquid. When molecules leave and return to the liquid at the same rate, equilibrium has been established; and the vapor space has become saturated. At any given storage pressure, the equilibrium percent of the volatile liquid vapor in the vapor space is directly proportional to the vapor pressure of the liquid.

Evaporation loss occurs only when vapors are emitted to the atmosphere. The amount of evaporation loss is a function of the rate of emission to the atmosphere and the period of time involved. Primary factors affecting the rate of emission are: true vapor pressure of the liquid at storage temperatures, temperature changes in the tank, tank outage, tank diameter, schedule of tank fillings and emptyings, tank conditions, and type of tank. Saturation and diffusion effects play relatively small parts in the mechanism of the loss and can be neglected for all practical purposes.

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The true vapor pressure (TVP) *at storage temperature* in a tank directly affects the rate of emissions to the atmosphere. Increasing TVP accelerates the rate of evaporation into any tank vapor space. Also, at saturation, a space contains proportionately more hydrocarbon vapors as the vapor pressure rises. Both of these factors increase the emission rate from a tank during any specific breathing or filling cycle.

There is no standardized procedure for directly determining the TVP of a hydrocarbon mixture. The standard procedure (ASTM D 323) for determining vapor pressure gives what is known as Reid vapor pressure (RVP) at a temperature of 100°F. TVP at any given temperature can be estimated from correlation charts relating RVP, TVP, temperature, and a fourth variable, ASTM distillation curve characteristics.

Definitions and Significance of Terms

Vapor Pressure

Vapor pressure is a measure of the force that tends to vaporize any volatile liquid. Molecular motion within the liquid is reponsible for this force and is related to the composition of the liquid. Smaller molecules are more active; thus, vapor pressures increase as the proportion of these low boiling (smaller molecule) components increase. Also, higher temperatures increase molecular motion, which results in higher vapor pressure.

Reid Vapor Pressure (RVP)

Reid vapor pressure is the absolute pressure in pounds per square inch determined at 100°F and a V/L ratio of 4 (i.e., ratio of vapor volume to liquid volume as defined in ASTM designation D 323) by using apparatus and procedures as standardized by the American Society for Testing and Materials. Thus, RVP is the vapor pressure of a sample which has had its composition changed because of the vaporization required to saturate the vapor space of the bomb.

True Vapor Pressure (TVP)

True vapor pressure is the vapor pressure of a liquid at a specified temperature, when the composition of the liquid is not changed by the vaporization that occurs in most measuring procedures. With mixtures, such vaporization results in lowering of the measured pressure.

Vaporization from a hydrocarbon mixture lowers the vapor pressure of the liquid because the higher vapor pressure components vaporize more readily, leaving the liquid richer in the lower vapor pressure components. Thus, for motor gasolines and similar wide-boiling range mixtures (mixtures containing components with a wide range of vapor pressures), TVP at 100°F may be significantly higher than RVP because some vaporization occurs as an inherent part of making the Reid test. For a pure compound, vaporization will not change the pressure; and TVP will equal RVP.

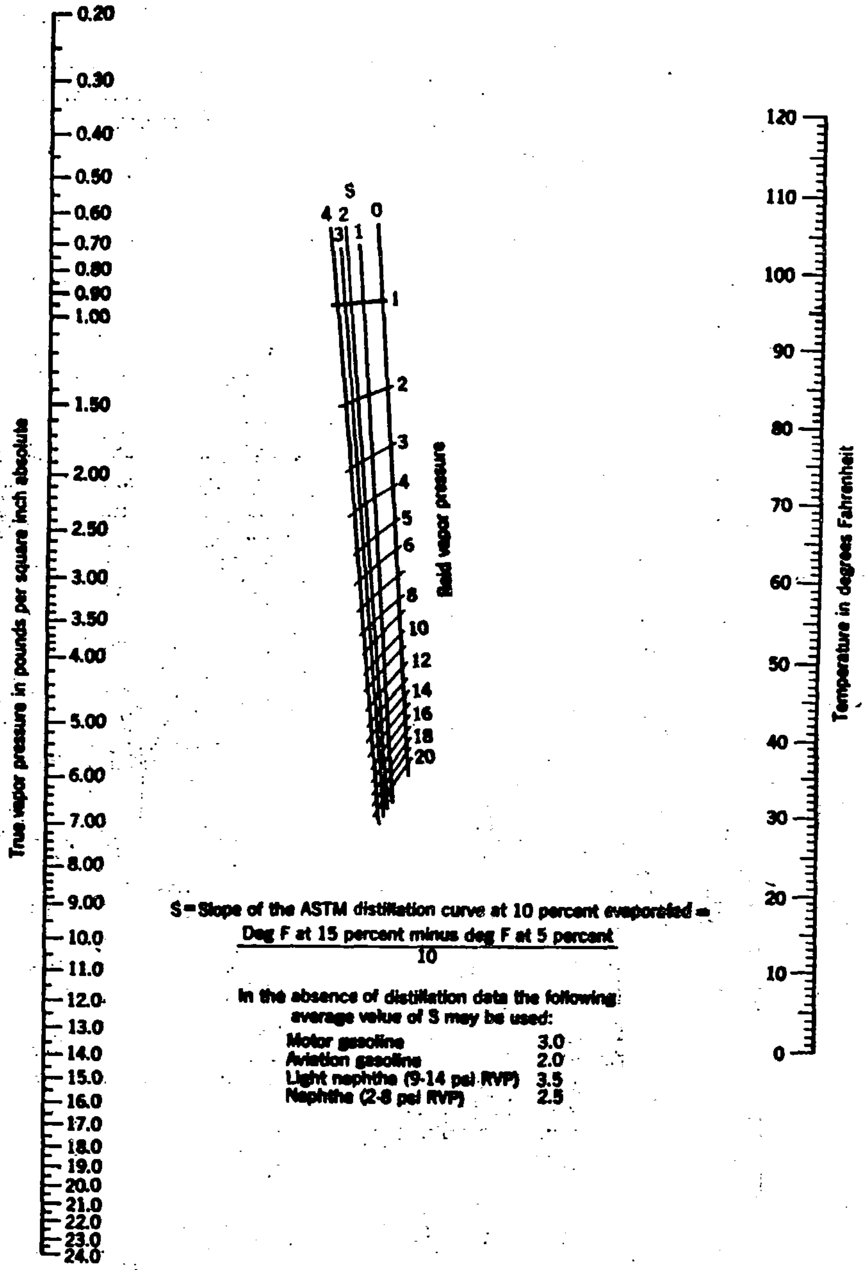

Figure 1. Vapor pressures of gasolines and finished petroleum products—1 lb. to 20 lb. RVP (API Bulletin 2518).

TVP can be estimated from correlations relating it to RVP and ASTM distillation curve (boiling range) characteristics. Charts in Figures 1 and 2 show this relationship for gasolines and crude oils over a wide range of temperatures.

Partial Pressure

The partial pressure of hydrocarbon in a vapor space is a measure of the force exerted by the hydrocarbon molecules striking the confining walls. Air molecules, usually present in petroleum storage tanks, similarly generate a partial pressure. The sum of all partial pressures equals the total pressure of the system. The partial pressure of any component is proportionate to its volumetric fraction of the vapor space.

In petroleum storage tanks, a space normally is in contact with the liquid which emits the hydrocarbon vapor. Equilibrium exists when partial pressure of the hydrocarbon vapor equals the vapor pressure of the liquid and the rates of vaporization and condensation are equal.

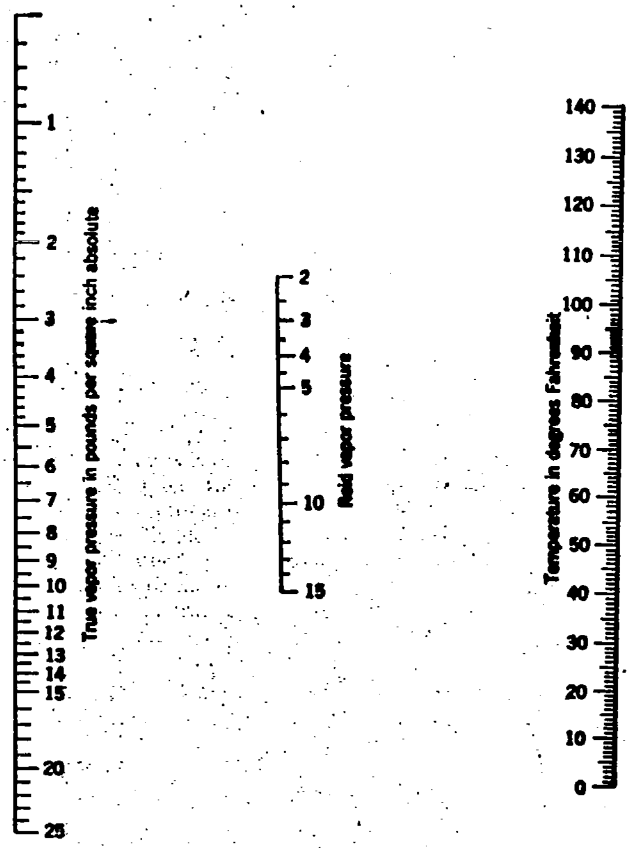

Figure 2. Vapor pressures of crude oil (API Bulletin 2518).

Saturation of Vapor Space

Vapor space in a tank, with respect to a given component, is said to be saturated when equilibrium exists between the component and the vapor and liquid phases under given conditions of temperature and pressure, and composition of the vapor space is uniform throughout.

Degree of saturation is the percentage of saturation with respect to a given component which prevails at any given time or location under normal equilibrium conditions.

Diffusion is the molecular motion which tends to uniformly distribute any component throughout a vapor space. Diffusion is one way by which newly vaporized hydrocarbons distribute themselves throughout a vapor space in an effort to saturate it.

Vaporization is the process whereby a liquid changes to a vapor, either with or without boiling.

Condensation is the reverse of vaporization, when a vapor changes to a liquid.

Conduction is a transfer of heat from one part of a body to another part of the same body without involving motion between parts of the body. Heat coming from outside a petroleum storage tank passes through the tank walls and to the liquid or vapor by conduction.

Convection is the transfer of heat by the movement of fluids induced either mechanically or by temperature differences.

Radiation is the transfer of heat from one body to another, not in contact with it, by means of wave motion. The rate of absorption of radiant energy by a body depends upon its area and surface reflective properties, exposure, and the temperature difference. Solar radiation is the chief source of radiant heating of conventional petroleum storage tanks.

Factors Necessary for Evaporation Loss

Two conditions must be present for evaporation to occur:

1. Heat must be supplied, and
2. The vapor evolved must not be allowed to accumulate.

Therefore, to reduce atmospheric emissions from a petroleum storage tank, we must:

1. Reduce the heat input, and
2. Contain the hydrocarbon vapor.

The total amount of atmospheric emissions from a tank depends upon the rate of evaporation loss and the time involved. Factors affecting the rate of evaporation loss are: true vapor pressure, temperature changes in the tank, tank outage, tank diameter, schedule of the tank fillings and emptyings, mechanical condition of tank, and type of tank. A fixed roof tank without a vapor conservation system is the least efficient in controlling atmospheric emissions. Saturation and diffusion effects are only parts of the loss mechanism and are classed as dependent or secondary variables.

True Vapor Pressure

True vapor pressure affects the rate of emission because it is the basic force causing vaporization; it changes with liquid composition and temperature. TVP at storage temperatures is all-important. For hydrocarbon mixtures, this decreases with evaporation because of the change in liquid composition. TVP is usually determined from correlations relating it to Reid vapor pressure (RVP).

The effect of TVP on rate of breathing loss from a fixed roof tank involves two internal considerations—saturation concentration and diffusion and convection factors. The maximum concentration of hydrocarbons in the expelled vapor, known as the saturation concentration, increases in direct proportion to TVP. It follows that, if vented vapors were fully saturated, evaporation loss would increase rapidly as TVP approaches tank relieving pressure (a boiling condition). However, the diffusion and convection of hydrocarbon vapor from the liquid surface to the vapor space is too slow to fully saturate it. Experience shows that vapors vented during normal tank breathing are usually only 80 to 90% saturated. Thus, the driving force can be looked upon as being the TVP of the liquid minus the partial pressure of the hydrocarbons in the vapor space. As TVP rises, this driving force will rise in direct proportion, if percentage saturation in the vapor space remains constant. Thus, both the saturation consideration and the diffusion and convection consideration suggest that actual emission rates are directly proportionate to rising TVP.

Tank emissions while filling fixed roof tanks are directly proportionate to increased TVP because of the relationship between TVP and saturation concentration.

Temperature Changes in the Tank

Internal temperature changes brought about by atmospheric conditions can cause the tank vapor space to breathe. During the day, heat flowing through the roof and walls raises the vapor temperature and expands the volume. The pure thermal effect is augmented by vaporization of hydrocarbons from the tank contents during the same period.

The heat input also may increase the liquid surface temperature and accelerate vaporization. At night, the reverse processes shrink the vapor and cause an intake of air.

Heat also causes natural convection in the vapor space which promotes evaporation from the liquid surface and aids in dispersing the hydrocarbon vapor.

Tank Outage

The volume of vertical tank vapor spaces is directly proportionate to outage—the height of vapor space. For a fixed roof tank, higher outages mean greater emission rates because the larger vapor volume will breathe more. However, when outage is increased, heat input is not increased in direct proportion. Heat enters the vapor space through the tank wall, the area of which increases in direct proportion, and through the tank roof, the area of which remains unchanged. Furthermore, with added height of vapor space, resistance to transfer of hydrocarbon vapor from the liquid surface to the vent increases. Therefore, the average concentration of hydrocarbon in vented vapor should fall. Experience has confirmed that atmospheric emission rate will increase less than in direct proportion to increase in tank outage.

Tank Diameter

Tank diameter influences volume of vapor space and liquid surface condition, assuming constant tank height. Total atmospheric emissions from breathing is less than directly proportionate to increase in vapor volume because of the less-than-proportionate increase in area for heat transfer into the vapor space. Furthermore, increasing tank diameter should reduce the temperature rise of the liquid surface because the rising hot stock, i.e., that in contact with the tank wall, must spread in a thinner film over the surface area.

Tank Conditions

Mechanical condition is another factor affecting emission rates of tanks. Open vents result in high emissions when gusty or turbulent winds cause rapid pressure changes in tanks in which volatile liquids are stored. Rapid emissions occur as short puffs. Any hole in the tank roof, diaphragm, seal, or accessory results in the same type of emission.

Where there are two or more openings in the tank, emissions are further increased. Pressure differences, which result from wind or thermal effects, cause a constant flow of air through some openings into the vapor space and the outflow of vapor through other openings.

Type of Tank

The type of tank or storage system will affect the emission rate experienced. The amount of emission depends on the volume of vapor space available and pressure limitations of the equipment.

If vapor space is allowed to change volume at constant pressure, emissions during the breathing cycle can be practically eliminated and emissions during fillings can be reduced. Extent of emissions reduction is dependent upon the amount of variable vapor space provided.

Sources of Emissions from Petroleum Tanks

There are six sources, or causes, of emissions from petroleum in storage: breathing loss, standing storage loss, filling loss, emptying loss, wetting loss, and boiling loss.

Breathing Loss

Vapor expelled from the tank because of the thermal expansion of existing vapors, expansion caused by barometric pressure changes, and/or increase in the amount of vapor from added vaporization in the absence of a liquid level change (except that which results from boiling) is defined as breathing loss.

Breathing loss takes place in most types of tanks and occurs when limits of *pressure* or *volume changes* are exceeded. Uninsulated fixed roof tanks, designed for only a few inches of water pressure or vacuum, suffer relatively higher breathing losses than tanks protected from a loss or gain in heat by reflective coating, burying, insulation, or shading. In pressure tanks, which operate at 2½ psig or higher, there is relatively little or no breathing loss. Variable vapor space tank systems reduce breathing losses. Floating roof tanks almost eliminate vapor spaces and little or no breathing loss occurs.

Standing Storage Loss

Vapor *emission* resulting from causes other than breathing or change in liquid level, is defined as standing storage loss. In floating roof tanks, the largest potential standing storage loss is attributed to improper fit of the seal and shoe to the shell. This condition exposes some liquid surface to the atmosphere. Wind affects this source of loss. Also, a small amount of vapor may permeate through the flexible membrane seal between shoes and roof. Other sources may be vapor escape from gaging hatches (*pressure vacuum*) vents, fittings, or other openings.

Filling Loss

Vapor expelled from a tank as result of filling, irrespective of the exact mechanism by which the vapors are produced, is common to all types of tanks except the floating roof tank and closed system pressure storage (such as for liquefied petroleum gas). It occurs when the pressure inside the tank exceeds the relief pressure. For fixed roof tanks, the relief pressure is low and emissions, when filling, can be relatively high. Emissions when filling variable vapor space tanks are less because these tanks have added vapor storage capacity. The pressure tank also promotes condensation of hydrocarbon vapors during filling.

Emptying Loss

Vapor emitted from the tank after liquid is removed is defined as emptying loss. Because vaporization lags behind the expansion of the vapor space during withdrawal, the partial pressure of the hydrocarbon vapor drops. Enough air enters during the withdrawal to maintain atmospheric pressure. When vaporization into the new air reaches equilibrium, the vapor volume exceeds the capacity of the vapor space. This increase in vapor volume causes the emission.

Emptying loss is common to all types of tanks except floating roof type and closed system pressure storage. Fixed roof tanks are most vulnerable. Pressure tanks and variable space tanks are less subject to emission, but encounter it if vapor storage capacity is exceeded.

Wetting Loss

Vaporization of liquid from a wetted tank wall, exposed when a floating roof is lowered by withdrawal of liquid, is defined as wetting loss. This loss is small.

Boiling Loss

Vapor expelled from the tank as a result of boiling of the liquid is boiling loss. A fixed roof tank is more subject to this emission than a pressure tank.

ATMOSPHERIC EMISSION CONTROL—PROCEDURES AND EQUIPMENT

There are four basic tank designs:

1. Fixed-roof tanks
2. Floating roof tanks
   - *A.* Conventional open type (most common)
   - *B.* Covered float tanks
     - (*a*) Internal floating covers for fixed-roof tanks
     - (*b*) Covered floating roof
3. Variable vapor space tanks
4. Pressure tanks

Each is designed for special storage requirements and has special requirements for accessories, maintenance, and efficient operation.

Fixed Roof Tanks

The minimum accepted standard for storage of volatile hydrocarbons is the fixed roof tank. Since it is usually the least costly to construct, it serves as a base in justifying expenditures necessary to construct conservation type tanks. It is designed to operate at only slight internal pressure or vacuum and is susceptible to emissions from breathing, filling, and emptying.

Accessory Equipment

The fixed roof tank has several openings in the roof for venting, gaging, and sampling. To maintain a gas-tight roof, accessory equipment must be provided.

The accessory for the vent opening is called a breather valve (*pressure vacuum*) relief or conservation vent. This device prevents the inflow of air or the escape of vapor until some pre-set vacuum or pressure is reached. Most breather valves, especially the metal type, allow some leakage below the pressure vacuum setting. A tight valve is important in reducing atmospheric emissions.

The pressure vacuum settings of a breather valve are dictated by the structural characteristics of the tank and must be within safe operating limits. A certain amount of pressure or vacuum beyond these settings is necessary to overcome pressure drop in order to obtain required flow. The pressure settings for vent valves to be installed on large tanks constructed in accordance with API Standard 650, "Welded Steel Tanks for Oil Storage" (1964), usually are limited to ½ ounce because the roof plates will start to lift when the pressure rises much above 1 oz. For small tanks, and all tanks having special structural features, the pressure range can be increased in accordance with the manufacturers' recommendations.

Maintenance of Accessory Equipment

To maintain accessories in a gas-tight condition, they should be inspected and restored periodically. Pallets of the metal-to-metal breather valves which become warped in service should be machined to restore a gas-tight fit. Defective diaphragms of valves should be replaced.

Liquid-seal breather valves may be affected by dilution or loss of liquid and may have to be inspected, cleaned, and maintained at frequent intervals. A loose-fitting gage hatch lid can be made nearly gas-tight by replacing the gasket or machining the seat. Flame arrestors and flash screens can become clogged with dust, rust, and ice. Such obstruction in the venting system can cause severe damage to the tank from excessive internal pressure or vacuum.

Choice of Paint

Painting is important in reducing atmospheric emissions as well as preserving the tank. Use of reflective paints will minimize heat input by reducing metal temperature. White paint is a simple and effective means of reducing emissions from fixed roof tanks.

Floating Roof Tanks

A floating roof tank is an effective conservation device for stocks of motor fuel volatility. The basic design virtually eliminates vapor space. This results in low emissions due to breathing, filling, and emptying.

Until recent years the most commonly used floating roof tank was the conventional open type floating roof tank. There are three basic designs of the open type floating roof tank used by the petroleum industry: pan, pontoon, and double-deck.

Pan-Type Floater

In this design a single deck covers most of the liquid surface. A seal is attached to rim of the deck. The deck slopes to the center for drainage. This type roof has found disfavor within the industry due to its instability. It is not recommended except for very special cases.

Pontoon Roof

This design was developed in 1928 to provide greater stability and roof buoyancy. The pontoons are arranged to provide floating stability under heavy loads of water and snow, and are acceptable designs for most purposes.

Double-Deck Roof

The roof in this case is a series of pontoons. This design is preferred because of its greater stability and insulating qualities.

Seal Design

The most critical feature in a floating roof tank is the fit of the seal. The usual seal consists of a relatively thin-gage shoe or ring supported against the tank shell around the edge of the roof. The bottom of the ring is below the liquid surface. The top is a few inches above the top rim of the roof. A piece of flame-retardant rubberized cloth closes the space between the ring and roof.

Another type of seal consists of a flexible tube, fastened to the roof and occupying the annular space between roof and shell. The tube is held on the liquid surface and completely eliminates the vapor space.

In tanks with riveted shells a somewhat higher emission rate for the more volatile stocks may occur because riveted heads and overlapping steel plates hold the ring away from the tank shell.

Maintenance of Tank

Efficient and safe operation of any mechanical device that moves intermittently requires inspection and maintenance at regular intervals. Shoes must fit well, seals must be in good condition, the roof should be level at all times. Breather valve and bleeder vent also must operate satisfactorily.

Seals should be inspected periodically for tightness and general condition. Sections of the seal that deteriorate should be replaced.

Design of Accessory Equipment

Two accessories are necessary to the operation of the floating roof tank: a breather valve for the rim space and a bleeder vent for the roof. One breather valve (sometimes two) is provided at the outer edge of all types. It is similar in design to that used on fixed roof tanks. The bleeder vent of the pontoon and double-deck tanks allows air trapped under the roof to escape before the roof floats and prevents a vacuum as the roof comes to rest on its supports.

Maintenance of Accessory Equipment

The following accessories should be inspected and replaced or repaired regularly:

a. breather valves
b. bleeder vents
c. gage hatches
d. other openings from which vapor may escape

Choice of Paint

The value of a highly reflective paint in reducing atmospheric emissions from floating roof tanks is less than for other types. Reflective paint on the pan-type roof may be justified because it will reduce the chance for boiling. It is not so important on the pontoon and double-deck roofs because those are designed to provide insulating barriers to heat transfer. Reflective paint on the shell may be useful because it may reduce boiling in the seal area and may help maintain a lower liquid temperature throughout the tank.

Internal Floating Covers for Fixed Roof Tanks

Installations of internal floating covers date from 1955 in France, and in recent years there has been a strong surge of interest in the United States in the internal floating cover as an economical and practical conservation device for fixed roof tanks.

Some types of internal floating covers currently available are listed below:

1. Aluminum cover.
2. Plastic coated-fabric cover supported on an inflatable circular tubular float.
3. Nylon fabric cover supported on a peripheral ring of aluminum floats.

Rapid installation is characteristic of all types of internal floating covers. No welding is required nor do door sheets have to be cut in the tank to make the installation. The tanks do have to be taken out of service and gas freed for installation of the semi-rigid types. If tank has been in leaded gasoline service, special cleaning and inspection will be required.

The inflatable ring design can be installed without taking the tank out of service. Its use is restricted to tanks which do not have roof support columns. These inflatable type covers are not normally available for tank diameters greater than 25 feet.

Each of the principal types is equipped with a resilient peripheral seal between the floating cover and the tank wall. Seal designs include a wiper type, tubular type, and resilient materials encased in chemical-resistant and wear-resistant envelopes. The effects of tank contents on seals must be considered, and it is important that any manufacturer be advised of the intended service.

As internal floating covers are very light, only antirotation cables are necessary to preserve alignment. Static charge is not a problem as in the cone-roof tank. Anti-static cables equalize any difference in potential between the floating cover and the tank shell.

Ample vapor space ventilation is essential. Vent areas equivalent to 0.20 square foot per foot of tank diameter is usually sufficient for all normal pumping rates. As a rule, a minimum of four vents is provided for aerodynamic efficiency. Maximum spacing of not over 32 feet between vents around the circumference is considered desirable. Damage to the roof by overfilling can be prevented by equipping the tank with an overflow.

Properly installed and fitted internal floating covers provide more effective vapor conservation than standard, open pontoon-type floating roofs. This is due to added protection from rain and wind. Installation of an internal floating cover is the least expensive method for converting an existing fixed roof to vapor conservation.

Covered Floating Roof Tank

The covered floating roof tank is not new. First installations were made in the late 1930's but has only gained wide acceptance in the 1960's. As the name implies, it is a fixed roof tank with a floating roof inside.

Basic design of the covered floater is a pan float in a fixed roof tank; the seal is usually of the less costly nonmetallic construction. The rolling stairway, roof drain, and wind girder of conventional floating roof design are eliminated. Possibility of a flammable mixture in the space between the fixed and floating roofs was probably a factor in delaying user acceptance. Modern designs provide ventilation by way of hooded openings in the fixed roof or in the upper portion of the tank shell. Ventilation area usually falls in the range of 0.06 to 0.20 square feet per foot of circumference. Jamming of the floating roof against the fixed roof by overfilling can be prevented by providing an overflow hole to release liquid above a certain level. This overflow is usually an indicator only and not designed to handle maximum filling rates.

Important advantages over the conventional open type floating roof are reduced maintenance and operating costs and improved product protection. There is no snow to remove and the freezing of seals to the shell is prevented. The floating roof drain is eliminated, and pollution problems which could occur due to its faulty operation are avoided. Conversion of a cone roof of any size to a covered floater is usually less costly than conversion to an open top floater. Practical designs which permit support columns to penetrate the float have been developed.

Deck and seal repairs are more difficult, and roof support column seals may cause problems. Column seal design varies with tank vendors and a number of each are in service. From the standpoint of losses, it is desirable to minimize the number of roof support columns. Costs may be adversely affected when this is done.

Variable Vapor Space Tanks

A variable vapor space tank is particularly suited to reducing emissions from breathing. Because of the effectiveness in reducing breathing loss, this tank has been widely accepted, particularly where tank throughput is low. Expanding vapors are stored temporarily in a gas holder device and vented to the atmosphere only when the holder capacity is exceeded. In cooling, the vapors then in the holder are drawn back into the tank. Variable vapor space capacity usually is sufficient so that one holder may be used in conjunction with interconnecting fixed roof tanks operating at substantially the same pressure. Emissions due to filling are not materially reduced.

Design of Tank

Two types of variable space tanks are used: the lifter roof and the flexible diaphragm. There are two types of lifter roof tanks: wet seal and dry seal. In each type, the roof is telescopic. Not being rigidly attached to the shell, the roof can move up or down as the vapor above the liquid expands or contracts.

With the wet seal lifter roof the upper part of the tank is surrounded by an annular space, called a "trough" or "launder," that contains a sealing liquid. A dip skirt extends from the roof into the liquid to provide a seal, while the roof is free to move up and down a distance of four to ten feet or more. The seal liquid may be water, light oil, or an anti-freeze solution.

The dry seal lifter roof tank operates similarly to the liquid seal lifter. Instead of a liquid seal, rubberized cloth or dry seal is used to retain the vapors as the roof moves. For both, the operating pressure ranges from 1½ ounces to 4 ounces per square inch depending upon the type, tank diameter and height of lift. Because this pressure controls the operation of the entire system, interconnected fixed roof tanks must be designed and constructed to withstand operating pressure, plus pressure drop in the system, plus a reserve to keep the vent from leaking.

Flexible diaphragm tanks serve the same purpose as lifter roof tanks by providing expansion capacity through movement of a diaphragm. There are two types: the integral unit and separate unit.

Maintenance of Tank

Keeping a variable vapor space tank or system gas tight requires careful maintenance. The level of sealing liquid in the wet seal lifter tank should be checked twice a year. Water, which may have condensed in the bottom of the dip ring of the roof. The launder should be filled with seal liquid to the design level.

Snow should not be permitted to accumulate on lifter roof tanks. The added pressure caused by snow at an average depth of 4 to 8 inches (depending upon the pressure setting of the vents) will cause the pressure vent portion of the volume control valve to open. Also, this increased pressure will cause vents in interconnected fixed roof tanks to leak or open. The entire system will become inoperative.

Design of Accessory Equipment

Breather valves are standard accessories for each tank in the variable vapor space system. Relief settings for breather valves on fixed roof tanks are slightly higher than those on conservation tanks. Because the variable vapor space capacity is not adequate to retain all vapor expelled during filling, the breather valve must accommodate vapor flow at maximum fill rate.

Each type of lifter roof tank generally has a volume control valve; some operate on vent valve only. This permits vapor to escape from the conservation tank when the roof has reached the extreme upper limit of travel. It also allows air to enter the tank to avoid drawing a vacuum beyond one inch of water.

Other accessories that aid in reducing emissions are (1) automatic gaging devices and temperature recorders, (2) mechanical control of vapor-line shutoff valve connected to regular gage hatch, and (3) gage wells.

Maintenance of Accessory Equipment

Maintenance of breather valves is even more important on a variable vapor space system than on a fixed roof tank alone because of the elevated pressures needed in the connected fixed roof tank. When a variable vapor-space unit is part of a multiple tank system, the leakage of one breather valve will tend to nullify the conservation effect of the entire system.

Choice of Paint

The same factors apply to this type of tank as were discussed under fixed roof tanks.

Pressure Tanks

Pressure tanks are storage tanks which withstand relatively large pressure variations without emitting hydrocarbon vapor. Some tanks withstand only the pressure variations caused by daily temperature changes; others prevent boiling of volatile stocks. Therefore, pressure tanks experience little or no emissions from breathing. Emissions, when filling, may vary widely, depending upon product characteristics, vent valve setting, and flow pipe arrangement.

Design of Tank

Two classes of pressure tanks are in general use: low-pressure tanks operating between 2.5 and 15 psig; and high-pressure tanks operating up to 250 psig or higher. Low-pressure tanks can tolerate only a slight vacuum, ordinarily 1 to 2 oz per square inch. Higher pressure tanks can be designed to withstand full vacuum.

Low-pressure tanks are constructed in many shapes and sizes depending upon the operating pressure range. One low-pressure tank, the noded hemispheroid, is designed for a pressure range of 2.5 to 5 psig. It consists of a cylindrical shell with curved plates in the top and bottom which may be either smooth or noded. In the plain hemispheroid, there are ring girders at the intersections of roof, shell, and bottom to withstand compression at points when the vessel is subjected to internal pressure.

The noded spheroid tank has been widely accepted for operating pressures ranging up to 15 psig. Storage capacities range from 40,000 to 120,000 barrels. These tanks have curved shells with internal ties and trusses and one or more nodes in the roof and bottom. Besides a ring girder and brackets around the external base of the shell, internal trusses support the curved portion of the shell and nodes in the roof. A center column serves as a roof support.

The spheroid is available for storage capacities ranging up to 40,000 barrels and operating pressures ranging up to 30 psig. Spheroids are smooth in appearance and have no internal framing.

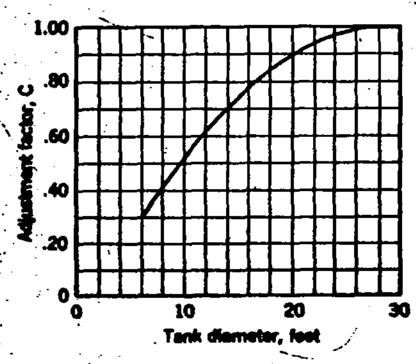

Figure 2. Adjustment factor for small diameter tanks (API Bulletin 2518).

Design of Accessories

Special gas-tight accessories are required because of high-pressure operations. Effectiveness and safety of the equipment depend upon careful selection of properly designed accessories.

Maintenance of Tank and Accessory Equipment

Pressure tanks should be inspected frequently to insure that tank and accessories are in gas-tight condition. Rupture of either pilot or main diaphragm of a pilot-operated relief valve will cause a valve to open below the set pressure. Valve performance should be checked. Diaphragms should be inspected for cracking or other signs of deterioration and replaced as necessary. Still-type breather valves should be inspected frequently to detect and correct freezing and sticking of pallets. Flame arrestors should be inspected and cleaned periodically to prevent clogging with dirt or ice.

Choice of Paint

To minimize pressure variations, tanks should be painted with a heat-reflective paint. Although color is not as critical as on fixed roof and variable vapor space tanks, white is commonly used.

Vapor Recovery Systems

These systems collect vapor from storage tanks and send it to a gas recovery plant. They have sensitive controls and remove vapor as pressure builds up during pumping or breathing. Vapor is compressed and recovered by absorption or condensation.

Refinery or natural gas is sometimes used for repressuring the vapor space in tanks when air or a corrosive atmosphere is undesirable in the vapor recovery system. Vapors are withdrawn as the internal pressure increases, and the repressuring gas is admitted to the tank when air normally would be drawn in. Some provision must be made to prevent collapse of structure when there is insufficient gas to maintain pressure.

Maintenance of Systems

Vapor recovery systems require that all tanks be kept gas tight and instrumentation and fittings be adequately maintained.

MEASUREMENT OF ATMOSPHERIC EMISSIONS FROM PETROLEUM STORAGE TANKS

Measurement of atmospheric emission can be accomplished in three basic ways:

1. decrease in stock volume
2. change in stock properties
3. measurement of vapors vented

Special techniques can increase the effectiveness of each approach.

API Bulletin 2512 (see Reference Sources) defines these test methods in detail. Part I of this bulletin discusses the basic approaches to measuring evaporation losses and offers guidance for selecting methods for use under specific conditions. Part II describes eight methods.

These methods are not simple or inexpensive. The petroleum industry has, therefore, correlated test data and developed equations for calculating evaporation loss rates.

Calculation of Hydrocarbon Vapor Emissions from Tanks

Many methods for calculating hydrocarbon emissions from petroleum storage tanks have been developed from experimental studies over the years. The American Petroleum Institute took an important step to coordinate knowledge in this field when it sponsored the "Symposium on Evaporation Loss" at the Institute's 32nd Annual Meeting in 1952. This led to establishment of the API Evaporation Loss Committee which, since that time, has studied and correlated experimental results to obtain useful control techniques and equations for predicting evaporation loss rates. Currently, this work has not been adopted as an API Standard; it is presented for information purposes only.

The correlations, formulae, and factors for calculating hydrocarbon vapor emissions published by the API Evaporation Loss Committee are used as the basis for this section of the report. Recommended methods of calculation follow.

Table I Paint factors.

Tank color		Paint factor, F_p	
Roof	Shell	Paint in good condition	Paint in poor condition*
White	White	1.00	1.15
Aluminum (specular)	White	1.04	1.18
White	Aluminum (specular)	1.16	1.24
Aluminum (specular)	Aluminum (specular)	1.20	1.29
White	Aluminum (diffuse)	1.30	1.38
Aluminum (diffuse)	Aluminum (diffuse)	1.39	1.46
White	Gray	1.30	1.38
Light gray	Light gray	1.33	
Medium gray	Medium gray	1.46	

* The values for paints in "poor condition" are provided only as a guide; it is not within the scope of this report to define poor conditions.

Fixed Roof Tanks

Breathing loss of gasoline from fixed roof tanks may be calculated from the following equation.

$$L_y = \left(\frac{24}{1000}\right)\left(\frac{P}{14.7 - P}\right)^{0.68} \times D^{1.73}H^{0.51}T^{0.50}F_pC \quad (1)$$

where

L_y = breathing loss, in barrels per year

P = true vapor pressure at bulk liquid temperature in psia, from Figure 1. Average liquid body temperature usually is available from gaging records; however, if this information is not readily available, it may be estimated by adding 5°F to the average ambient temperature from meteorological records

D = tank diameter, in feet

H = average outage, in feet, including a correction for roof volume

T = average daily ambient temperature change, in degrees F (difference between U. S. Weather Bureau average daily recorded maximum and minimum temperatures)

F_p = paint factor from Table I (from API Bulletin 2518).

C = adjustment factor for tank diameter as indicated in Figure 3 (from API Bulletin 2518).

Working Loss (filling and emptying loss) of gasoline from fixed roof tanks may be calculated from the following equation:

$$F = \frac{3PV}{10{,}000}K_T \quad (2)$$

where

F = working loss, in barrels
P = same as defined above
V = volume of liquid pumped into tanks in barrels
K_T = turnover factor as indicated in Figure 4 (from API Bulletin 2518).

Breathing loss of crude oil from fixed roof tanks may be calculated from the following equation:

$$L_y = K_c\left(\frac{24}{1000}\right)\left(\frac{P}{14.7 - P}\right)^{0.68} \times D^{1.73}H^{0.51}T^{0.50}F_pC \quad (3)$$

where K_c is factor to adjust gasoline breathing loss equation to breathing loss of crude oil — 0.58.

The remainder of the nomenclature is the same as defined for the gasoline equation except that the true vapor pressure, P, is determined from Figure 2.

Working loss of crude oil from fixed roof tanks may be calculated from the following equation:

$$F = \frac{2.25PV}{10{,}000}K_T \quad (4)$$

Nomenclature is the same as defined for Equation (2) except that the true vapor pressure (P) is from Figure 2.

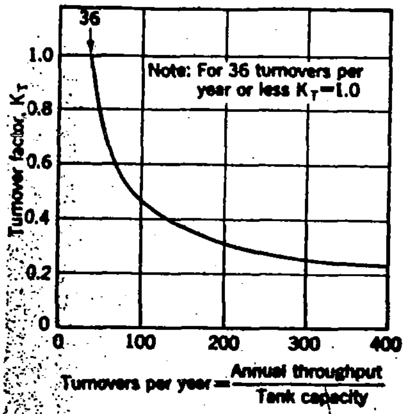

Figure 4. Effect of turnover on working loss (API Bulletin 2518).

Floating Roof Tanks

Standing storage evaporation loss may be calculated from the following equation:

$$L_s = K_t D^{1.5}\left(\frac{P}{14.7 - P}\right)^{0.7} \times V_w^{0.7} K_s K_c K_p \quad (5)$$

where

- L_s = standing storage evaporation loss, in barrels per year
- K_t = A tank-type factor which changes as follows:
  - K_t = 0.045 for welded tank with pan or pontoon roof, single or double seal
  - K_t = 0.11 for riveted tank with pontoon roof, double seal
  - K_t = 0.13 for riveted tank with pontoon roof, single seal
  - K_t = 0.13 for riveted tank with pan roof, double seal
  - K_t = 0.14 for riveted tank with pan roof, single seal
- D = tank diameter in feet (for tanks 150 ft or less in diameter, use $D^{1.5}$; for tanks larger than 150 ft. in diameter, use $150^{1.5}\left(\frac{D}{150}\right)$)
- P = true vapor pressure of the stock at its average storage temperature, in psia. (This may be determined from the Reid vapor pressure using appropriate conversion curves for finished products and crude oils in Figures 1 and 2)
- V_w = average wind velocity, in miles per hour
- K_s = a recommended seal factor: K_s = 1.00 for tight-fitting seals (typical of modern metallic and nonmetallic seals); K_s = 1.33 for loose-fitting seals (typical of seals built prior to 1942)
- K_c = a recommended factor distinguishing between gasoline and crude oil storage: K_c = 1.00 for gasoline; K_c = 0.75 for crude oil
- K_p = a recommended paint factor for color of shell and roof: K_p = 100 for light gray or aluminum; K_p = 0.90 for white

Variable Vapor Space Systems

Filling losses from variable vapor space systems can be estimated from the following formula:

$$F = \frac{3P}{10{,}000}(V_1 - 0.25V_2N) \quad (6)$$

where

- F = filling loss, barrels
- P = true vapor pressure at bulk liquid temperature in psia
- V_1 = volume of liquid pumped in, barrels
- V_2 = volume of expansion capacity, barrels
- N = number of transfers into the system

Conversions to Tons/Days

To place these values in terms more conventional in atmospheric quality control usage, the following formula is recommended:

$$E = \frac{LW}{730{,}000} \quad (7)$$

where

- E = hydrocarbon emissions (tons/day)
- L = total evaporation loss from tank (barrels/year)
- W = density of hydrocarbon vapors (lb/42-gallon barrel)

The loss equations presented here do not have API approval as standard procedures and are submitted for information only as recommended methods for calculating emissions to the atmosphere from petroleum storage tanks. These loss equations are based on a correlation of industry-wide test data.

REFERENCE SOURCES ON EVAPORATION LOSSES

API Bulletin

2512 Tentative Methods of Measuring Evaporation Loss from Petroleum Tanks and Transportation Equipment
2513 Evaporation Loss in the Petroleum Industry—Causes and Control
2514 Evaporation Loss from Tank Cars, Tank Trucks, and Marine Vessels
2515 Use of Plastic Foam to Reduce Evaporation Loss
2516 Evaporation Loss from Low Pressure Tanks
2517 Evaporation Loss from Floating Roof Tanks
2518 Evaporation Loss from Fixed Roof Tanks
2519 Use of Internal Covers for Fixed Roof Tanks to Reduce Evaporation Loss
2520 Use of Variable Vapor Space Systems to Reduce Evaporation Loss
2521 Use of Pressure Vacuum Vent Valves for Atmospheric Pressure Tanks to Reduce Evaporation Loss
2522 Comparative Methods for Evaluating Conservation Mechanisms for Evaporation Loss