SUPPLEMENT NO. 1 FOR COMPILATION OF AIR POLLUTANT EMISSION FACTORS

SECOND EDITION

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina
July 1973

INSTRUCTIONS

FOR INSERTING SUPPLEMENT NO. 1

INTO

COMPILATION OF AIR POLLUTANT EMISSION FACTORS

1. Replace undated page iii - iv with page iii - iv dated 7/73.
2. Replace undated page v - vi with page v - vi dated 7/73.
3. Replace undated page xiii - xiv with page xiii - xiv dated 7/73.
4. Replace undated page xv - xvi with page xv - xvi dated 7/73.
5. Replace page 4.3-1 - 4.3-2 dated 2/72 with pages 4.3-1 through 4.3-10 dated 7/73.
6. Replace page 4.4-1 - 4.4-2 dated 2/72 with pages 4.4-1 through 4.4-8.

PREFACE

This document reports data available on those atmospheric emissions for which sufficient information exists to establish realistic emission factors. The information contained herein is based on Public Health Service Publication 999-AP-42, *Compilation of Air Pollutant Emission Factors*, by R. L. Duprey, and on a revised and expanded version of *Compilation of Air Pollutant Emission Factors* that was published by the Environmental Protection Agency in February 1972. The scope of this second edition has been broadened to reflect expanding knowledge of emissions.

Chapters and sections of this document have been arranged in a format that permits easy and convenient replacement of material as information reflecting more accurate and refined emission factors is published and distributed. To speed dissemination of emission information, chapters or sections that contain new data will be issued – separate from the parent report – whenever they are revised.

To facilitate the addition of future materials, the punched, loose-leaf format was selected. This approach permits the document to be placed in a three-ring binder or to be secured by rings, rivets, or other fasteners; future supplements or revisions can then be easily inserted. The lower left- or right-hand corner of each page of the document bears a notation that indicates the date the information was issued.

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ACKNOWLEDGMENTS

Because this document is a product of the efforts of many individuals, it is impossible to acknowledge each individual who has contributed. Special recognition is given, however, to Mr. Richard Gerstle and the staff of Resources Research, Inc., who provided a large part of the efforts that went into this document. Their complete effort is documented in their report for contract number CPA-22-69-119.

Environmental Protection Agency employees M. J. McGraw, A. J. Hoffman, J. H. Southerland, and R. L. Duprey are also acknowledged for their efforts in the production of this work. Bylines identify the contributions of individual authors who revised specific sections and chapters.

Issuance	Release Date
Compilation of Emission Factors, Second Edition	4/73
Supplement No. 1	7/73
Section 4.3, Storage of Petroleum Products	
Section 4.4, Marketing and Transportation of Petroleum Products	

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4.3 STORAGE OF PETROLEUM PRODUCTS

Revised by William M. Vatavuk
and Richard K. Burr

Fundamentally, the petroleum industry consists of three operations (1) crude oil production, (2) petroleum refining, and (3) transportation and marketing of finished products. Associated with these operations are evaporative emissions of various organic compounds, either in pure form or as mixtures.

From an air pollution standpoint, the petroleum industry is defined in terms of two kinds of evaporative losses: (1) storage and (2) marketing and transportation. (See Figure 4.4-1 for schematic of the industry and its points of emission.)

4.3.1 Process Description[1-5]

Petroleum storage evaporation losses are associated with the containment of liquid organics in large vessels at oil fields, refineries, and product distribution terminals.

Six basic tank designs, are used for petroleum storage vessels: (1) fixed-roof (cone roof), (2) floating roof (single deck pontoon and double deck), (3) covered floating roof, (4) internal floating cover, (5) variable vapor space, and (6) pressure (low and high).

The fixed roof tank (Figure 4.3-1) is the least expensive vessel for storing certain hydrocarbons and other organics. This tank generally consists of a steel, cylindrical container with a conical roof and is equipped with a pressure/vacuum vent, designed to operate at slight deviations (0.021 Mg/m^2 maximum) from atmospheric pressure.

0.029869 psi, 0.827 in. H_2O

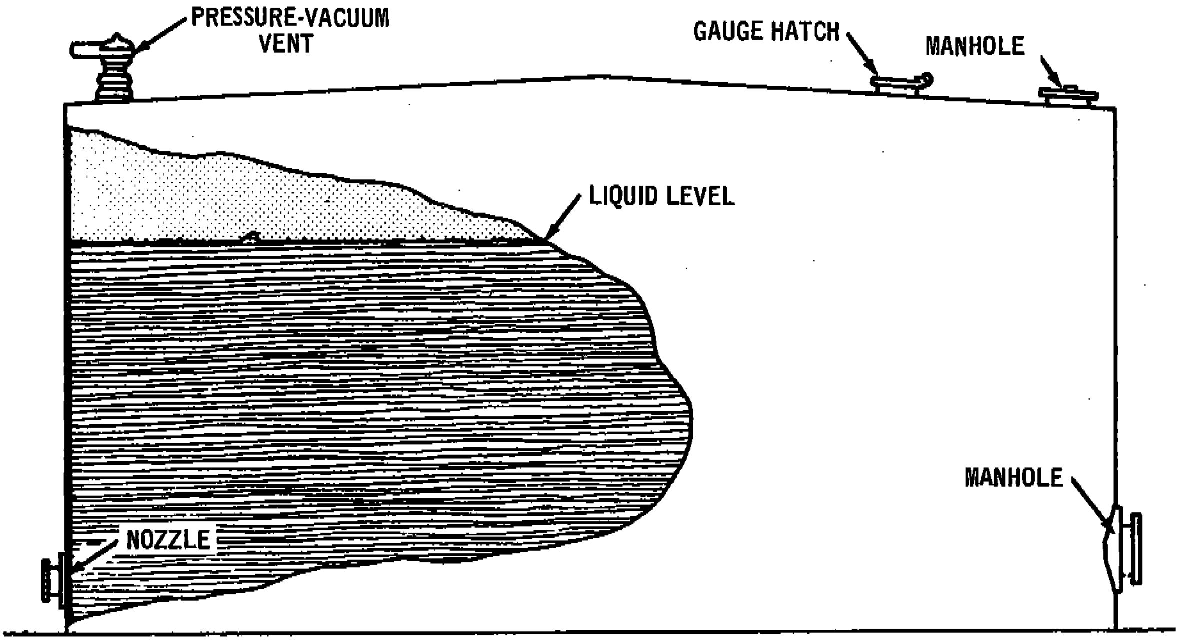

Figure 4.3-1. Fixed roof storage tank.

A floating roof tank is a welded or riveted circular vessel with an external float-type pan or pontoon roof (single- or double-deck) equipped with single or double mechanical seals (Figure 4.3-2).

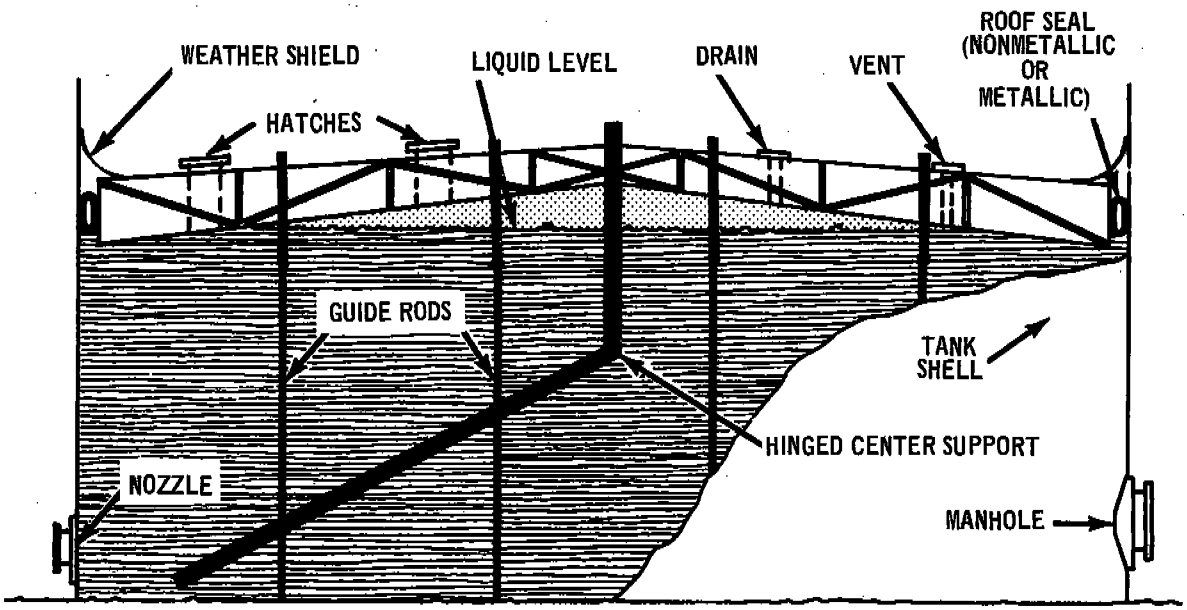

Figure 4.3-2. Double-deck floating roof storage tank (nonmetallic seal).

The floating roof prevents the formation of a volume of organic vapor above the liquid surface, which would otherwise be vented or displaced during filling and emptying. The seal, which is designed to close the annular space between the roof and vessel wall, consists of a relatively thin-gauge shoe ring supported against the tank shell around the roof.

The covered floating roof tank, simply a steel pan-type floating roof inside a fixed roof tank. is designed to reduce product losses and maintenance costs. Another type, the internal floating cover tank, contains a floating cover constructed of a material other than steel. Materials used include aluminum sheeting, glass-fiber-reinforced polyester sheeting, and rigid plastic foam panels.

The lifter and flexible diaphragm variable vapor space tanks are also used to reduce vapor losses (Figure 4.3-3). With the lifter tank, the roof is telescopic; i.e., it can move up or down as the vapor above the liquid surface expands or contracts. Flexible diaphragm tanks serve the same function through the expansion and contraction of a diaphragm.

Pressure tanks are especially designed for the storage of volatile organics under low (17 to 30 psia or 12 to 21 Mg/m^2) or high (up to 265 psia or 186 Mg/m^2) pressure and are constructed in many sizes and shapes, depending on the operating range. The most popular are the noded hemi-spheroid and the noded spheroid for low pressure and the spheroid for high pressure. Horizontal cylindrical forms are also commonly used for high pressure storage.

4.3.2 Emissions and Controls[1-3,5-7]

There are six sources of emissions from petroleum in storage.

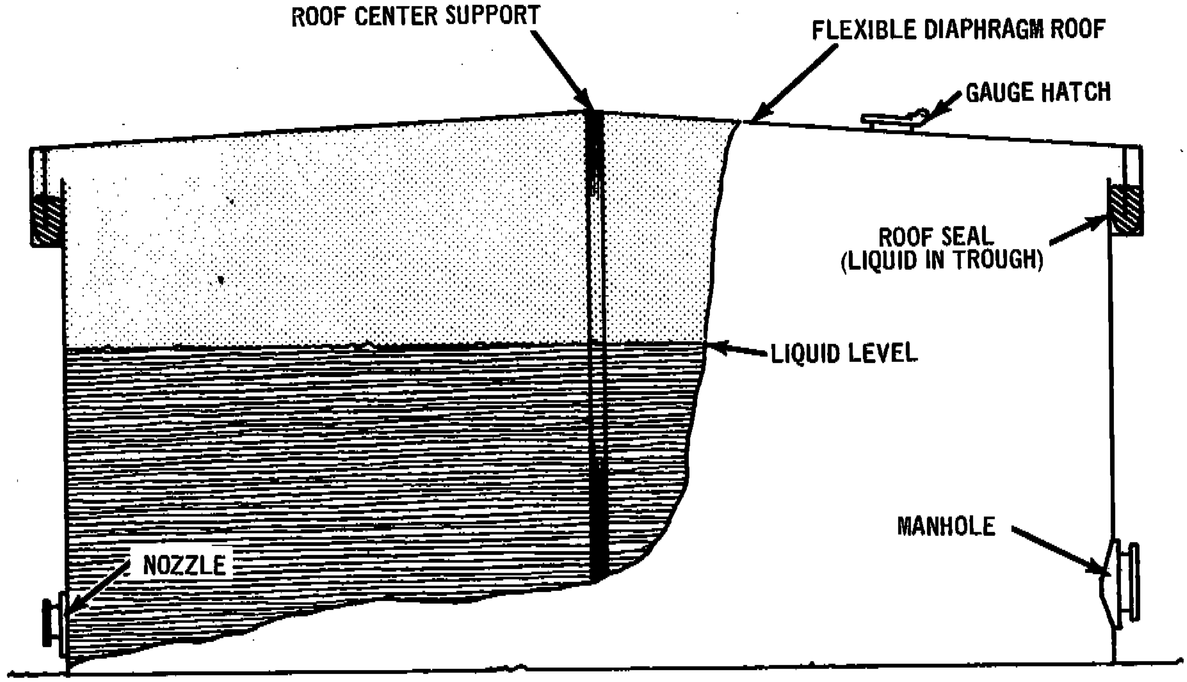

Figure 4.3-3. Variable vapor storage tank (wet-seal lifter type).

Breathing losses are associated with fixed roof tanks and consist of vapor expelled from the tank because of thermal expansion, barometric pressure changes, and added vaporization of the liquid.

Working losses consist of hydrocarbon vapor expelled from the vessel as a result of emptying or filling operations. Filling losses represent the amount of vapor (approximately equal to the volume of liquid input) that is vented to the atmosphere through displacement. After liquid is removed, emptying losses occur, because air drawn in during the operation results in growth of the vapor space. Both filling and emptying (together called "working") losses are associated primarily with fixed roof and variable vapor space tanks. Filling losses are also experienced from low pressure tankage, although to a lesser degree than from fixed roof tanks.

Primarily associated with floating roof tanks, standing storage losses result from the improper fit of the seal and shoe to the tank shell.

Wetting losses with floating roof vessels occur when a wetted tank wall is exposed to the atmosphere. These losses are negligible.

Finally, boiling loss is the vapor expelled when the temperature of the liquid in the tank reaches its boiling point and begins to vaporize.

The quantity of evaporation loss from storage tanks depends on several variables:

(1) True vapor pressure of the liquid stored,
(2) Diurnal temperature changes in the tank vapor space,

(3) Height of the vapor space (tank outage),
(4) Tank diameter,
(5) Schedule of tank fillings and emptyings,
(6) Mechanical condition of tank, and
(7) Type of paint applied to outer surface.

The American Petroleum Institute has developed empirical formulae, based on extensive testing, that correlate breathing, working, and standing storage losses with the above parameters for fixed roof, floating roof, and variable vapor space vessels.

Fixed roof breathing losses can be estimated from:

$$B = \frac{2.74\ WK}{V_c} \left(\frac{P}{14.7-P}\right)^{0.68} D^{1.73}\ H^{0.51}\ \Delta T^{0.50}\ F_p C \qquad (1)$$

where:
- B = Breathing loss, lb/day-10^3 gal capacity
- P = True vapor pressure at bulk liquid temperature, psia
- D = Tank diameter, feet
- H = Average vapor space height, including correction for roof volume, feet
- ΔT = Average daily ambient temperature change, °F
- F_p = Paint factor, determined from field tests (see Table 4.3-1)
- C = Adjustment factor for tanks smaller than 20 feet in diameter (see Figure 4.3-4)
- V_c = Capacity of tank, barrels
- K = Factor dependent on liquid stored:
  - = 0.014 for crude oil
  - = 0.024 for gasoline
  - = 0.023 for naphtha jet fuel (JP-4)
  - = 0.020 for kerosene
  - = 0.019 for distillate oil
- W = Density of liquid at storage conditions, lb/gal

Table 4.3-1. PAINT FACTORS FOR FIXED ROOF TANKS[a]

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

[a]Reference 2.
[b]Estimated from the ratios of the seven preceeding paint factors.

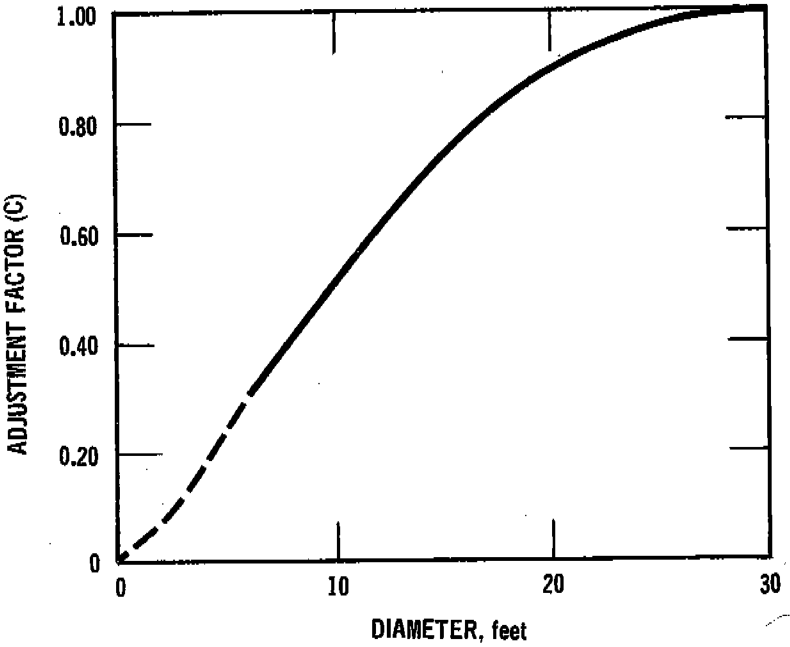

Figure 4.3-4. Adjustment factor for small-diameter fixed roof tanks.[2]

Breathing losses of petrochemicals from fixed roof tanks can be estimated from the respective gasoline loss factor, calculated at their storage temperature:

$$B_p = 0.08 \left(\frac{M_p}{W_G}\right)\left(\frac{P_p}{P_G}\right) B_G \tag{2}$$

where: B_p, B_G, = Breathing losses of petrochemical (p) and gasoline (G), lb/day-10^3 gal

M_p = Molecular weight of petrochemical (p), lb/mole

W = Liquid density of gasoline, lb/gal

P_p, P_G = True vapor pressures of petrochemical (p) and gasoline (G) at their bulk storage temperature, psia

This same correlation can also be used to estimate petrochemical working loss, standing storage loss, or any other kind of loss from any storage tank.

A correlation for fixed roof tank working loss (combined emptying and filling) has also been developed:

$$F_f = 1000\,\text{WmP}\left(\frac{180 + N}{6N}\right) \tag{3}$$

where: F_f = Working loss, lb/10^3 gal throughput

P = True vapor pressure at bulk liquid temperature, psia

N = Number of tank turnovers per year (ratio of annual throughput to tank capacity)

m = Factor dependent on liquid stored:

= 3×10^{-4} for gasoline

= 2.25×10^{-4} for crude oil

= 3.24×10^{-4} for naphtha jet fuel (JP-4)

= 2.95×10^{-4} for kerosene

= 2.76×10^{-4} for distillate oil

Standing storage losses from floating roof tanks can be calculated from:

$$S = \frac{2.74\, WK_t}{V_c} D^{1.5} \left(\frac{P}{14.7 - P}\right)^{0.7} V_w^{\,0.7}\; K_s K_c K_p \tag{4}$$

where: S = Standing storage evaporation loss, lb/day-10^3 gal capacity

K_t = Factor dependent on tank construction:

= 0.045 for welded tank, pan/pontoon roof, single/double seal

= 0.11 for riveted tank, pontoon roof, double seal

= 0.13 for riveted tank, pontoon roof, single seal

= 0.13 for riveted tank, pan roof, double seal

= 0.14 for riveted tank, pan roof, single seal

D = Tank diameter, feet; for $D \geq 150$ feet (45.8 m) use "$D\sqrt{150}$" instead of "$D^{1.5}$"

V_w = Average wind velocity, mi/hr

K_s = Seal factor:

= 1.00 for tight-fitting, modern seals

= 1.33 for loose-fitting, older seals (typical of pre-1942 installation)

K_c = Factor dependent on liquid stored:

= 1.00 for gasoline

= 0.75 for crude oil

= 0.96 for naphtha jet fuel (JP-4)

= 0.83 for kerosene

= 0.79 for distillate oil

K_p = Paint factor for color of shell and roof:

= 1.00 for light gray or aluminum

= 0.90 for white

Finally, filling losses from variable vapor space systems can be estimated by:

$$F_v = \frac{1000\ WmP}{V_t}\ (V_t - 0.25V_eN) \quad (5)$$

where: m = Factor dependent on liquid stored (same as equation 3)

F_v = Filling loss, lb/10^3 gal throughput

V_t = Volume of liquid throughput, bbl/year

V_e = Volume of expansion capacity, barrels

N = Number of turnovers per year

W = Density of liquid at storage conditions, lb/gal

Equations 1 through 5 can be used to calculate evaporative losses, provided the respective parameters are known. For those cases where such quantities are unknown or for quick loss estimates, however, Table 4.3-2 provides typical emission factors. Refinement of emission estimates by using these loss correlations may be desirable in areas where these sources contribute a substantial portion of the total evaporative emissions or are of major consequence in affecting the air quality.

The control methods most commonly used with fixed roof tanks are vapor recovery systems, which collect emissions from storage vessels and send them to gas recovery plants. The four recovery methods used are liquid absorption, vapor compression, vapor condensation, and adsorption in activated charcoal or silica gel.

Overall control efficiencies of vapor recovery systems vary from 90 to 95 percent, depending on the method used, the design of the unit, the organic compounds recovered, and the mechanical condition of the system.

In addition, water sprays, mechanical cooling, underground liquid storage, and optimum scheduling of tank turnovers are among the techniques used to minimize evaporative losses by reducing tank heat input.

Product	Vapor pressure ratio (P/P_G)	Mole wt (M) (lb/mole)	Floating roof: Standing storage loss: "New tank" conditions: lb/day-10^3 gal	"New tank" conditions: kg/day-10^3 liter	"Old tank" conditions: lb/day-10^3 gal	"Old tank" conditions: kg/day-10^3 liter
Crude oil[c]		64.5	0.029	0.0034	0.071	0.0086
Gasoline[c]		56.8	0.033	0.0040	0.088	0.011
Naphtha jet fuel (JP-4)[c]		63.3	0.012	0.0014	0.029	0.0034
Kerosene[c]		72.7	0.0052	0.00063	0.012	0.0015
Distillate fuel[c]		72.7	0.0052	0.00063	0.012	0.0015
Acetone	0.543	58.1	0.014	0.0017	0.036	0.0043
Ammonium hydroxide (28.8 % solution)	1.53	35.1	0.023	0.0028	0.062	0.0074
Benzene[c]	0.2108	78.1	0.0074	0.00089	0.020	0.0023
Isobutyl alcohol	0.0263	74.1	0.00086	0.00010	0.0023	0.00028
Tertbutyl alcohol	0.0843	74.1	0.0029	0.00034	0.0074	0.00089
Carbon tetrachloride	0.264	153.8	0.018	0.0021	0.048	0.0057
Cyclohexane[c]	0.230	84.2	0.0083	0.0010	0.022	0.0027
Cyclopentane[c]	0.776	70.1	0.024	0.0028	0.062	0.0074
Ethyl acetate	0.210	88.1	0.0081	0.00097	0.021	0.0025
Ethyl alcohol	0.120	46.1	0.0024	0.00029	0.0064	0.00074
Freon II	2.01	137.4	0.12	0.014	0.32	0.038
$_n$Heptane[c]	0.103	100.2	0.0045	0.00054	0.012	0.0014
$_n$Hexane[c]	0.353	86.2	0.013	0.0016	0.036	0.0043
Hydrogen cyanide	1.42	27.0	0.017	0.0020	0.043	0.00051
Isooctane[c]	0.112	114.2	0.0055	0.00066	0.015	0.0018
Isopentane[c]	1.86	72.2	0.057	0.0069	0.15	0.018
Isopropyl alcohol	0.0933	60.1	0.0024	0.00029	0.0064	0.00077
Methyl alcohol	0.272	32.0	0.0038	0.00046	0.010	0.0012
$_n$Pentane[c]	1.26	72.2	0.038	0.0046	0.10	0.012
Toluene[c]	0.0594	92.1	0.0024	0.00029	0.0062	0.00074

[a]References 2, 3, 6, and 7.
[b]Factors based on following conditions:
Storage temperature: 63 °F (17.2 °C).
Daily ambient temperature change: 15°F (-9.5°C).
Wind velocity: 10 mi/hr (4.5 m/sec).

	Reid vapor pressure: psia	Reid vapor pressure: Mg/m²	True vapor pressure: psia	True vapor pressure: Mg/m²
Crude oil	7.0	4.9	4.6	3.2
Gasoline	10.5	7.4	5.8	4.1
Naphtha jet fuel (JP-4)	2.5	1.75	1.2	0.84
Kerosene	≤0.5	≤0.35	≤0.5	≤0.35
Distillate oil	≤0.5	≤0.35	≤0.5	≤0.35

Typical fixed- and floating-roof tanks
Diameter: 90 ft (27.4 m) for crude, JP-4, kerosene, and distillate; 110 ft (33.6 m) for gasoline and all petrochemicals.
Height: 44 ft (13.4 m) for crude, JP-4, kerosene, and distillate; 48 ft (14.6 m) for gasoline and all petrochemicals.
Capacity: 50,000 bbl (7.95 x 10^6 liter) for crude, JP-4, kerosene, and distillate; 67,000 bbl (10.65 x 10^6 liter) for gasoline and all petrochemicals.
Outage: 50 percent of tank height.
Turnovers per year: 30 for crude oil; 13 for all others.

[c]Indicates petroleum products whose evaporative emissions are exclusively hydrocarbons (i.e., compounds containing only the elements hydrogen and carbon).

FACTORS FOR STORAGE TANKS[a, b]
RATING: A

Fixed roof						Variable vapor space	
Breathing loss				Working loss		Working loss	
"New tank" conditions		"Old tank" conditions					
lb/day-10^3 gal	kg/day-10^3 liter	lb/day-10^3 gal	kg/day-10^3 liter	lb/10^3 gal throughput	kg/10^3 liter throughput	lb/10^3 gal throughput	kg/10^3 liter throughput
0.15	0.018	0.17	0.020	7.3	0.88	Not used	Not used
0.22	0.026	0.25	0.031	9.0	1.1	10.2	1.2
0.069	0.0033	0.079	0.0095	2.4	0.29	2.3	0.28
0.036	0.0043	0.041	0.0048	1.0	0.12	1.0	0.12
0.036	0.0043	0.041	0.0048	1.0	0.12	1.0	0.12
0.093	0.011	0.10	0.013	3.7	0.45	4.2	0.51
0.16	0.018	0.18	0.021	6.3	0.76	7.1	0.86
0.050	0.0057	0.057	0.0069	2.0	0.24	2.3	0.27
0.0057	0.00067	0.0064	0.0079	0.23	0.028	0.26	0.031
0.018	0.0021	0.021	0.0026	0.74	0.90	0.83	0.099
0.12	0.014	0.14	0.016	4.8	0.58	5.4	0.63
0.057	0.0067	0.064	0.0079	2.3	0.28	2.6	0.31
0.16	0.019	0.18	0.022	6.4	0.77	7.2	0.87
0.055	0.0062	0.062	0.0074	2.2	0.27	2.5	0.30
0.016	0.0019	0.018	0.0022	0.65	0.079	0.73	0.089
0.81	0.098	0.92	0.11	32.4	3.9	36.7	4.4
0.031	0.0036	0.033	0.0040	1.2	0.15	1.4	0.16
0.088	0.010	0.10	0.012	3.6	0.43	4.0	0.49
0.11	0.013	0.13	0.015	4.5	0.54	5.1	0.61
0.038	0.0043	0.043	0.0051	1.5	0.18	1.7	0.21
0.39	0.047	0.45	0.053	15.7	1.9	17.8	2.1
0.016	0.0019	0.019	0.0022	0.66	0.080	0.74	0.090
0.026	0.0031	0.029	0.0034	1.0	0.13	1.2	0.14
0.26	0.032	0.30	0.036	10.6	1.3	12.0	1.4
0.016	0.0019	0.018	0.022	0.64	0.077	0.73	0.087

Typical floating-roof tank
Paint factor (K_p): New tank-white paint, 0.90; Old tank-white/aluminum paint, 0.95.
Seal factor (K_s): New tank-modern seals, 1.00; Old tank-50 percent old seals, 1.14.
Tank factor (K_t): New tank-welded, 0.045; Old tank-50 percent riveted, 0.088.

Typical fixed-roof tank
Paint factor (F_p): New tank-white paint, 1.00; Old tank-white/aluminum paint, 1.14.

Typical variable vapor space tank
Diameter: 50 ft (15.3 m).
Height: 30 ft (9.2 m).
Capacity: 10,500 bbl (1.67 x 10^6 liter).
Turnovers per year: 6.

REFERENCES FOR SECTION 4.3

1. Control of Atmospheric Emissions from Petroleum Storage Tanks. Petroleum Committee, Air Pollution Control Association. J. Air Pol. Control Assoc. *21*(5):260-268, May 1971.

2. Evaporation Loss from Fixed Roof Tanks. American Petroleum Institute, New York, N.Y. API Bulletin Number 2518. June 1962.

3. Evaporation Loss from Floating Roof Tanks. American Petroleum Institute, New York, N.Y. API Bulletin Number 2517. February 1962.

4. Evaporation Loss in the Petroleum Industry – Causes and Control. American Petroleum Institute, New York, N.Y. API Bulletin Number 2513. February 1959.

5. Personal communication with personnel in Engineering Services Branch, Emission Standards and Engineering Division, Office of Air Quality Planning and Standards, Environmental Protection Agency, Research Triangle Park, N.C. November 1972.

5. Petrochemical Evaporation Loss from Storage Tanks. American Petroleum Institute, New York, N.Y. API Bulletin Number 2523. November 1969.

7. Use of Variable Vapor Space Systems to Reduce Evaporation Loss. American Petroleum Institute, New York, N.Y. API Bulletin Number 2520. September 1964.

4.4 MARKETING AND TRANSPORTATION OF PETROLEUM PRODUCTS

by William M. Vatavuk

4.4.1 Process Description[1]

As Figure 4.4-1 indicates, the marketing and transportation of petroleum products involves many distinct operations, each of which can represent a source of evaporation loss.

For example, after gasoline is refined, it is transported first via pipeline, rail, ship, or barge to intermediate storage and then to regional marketing terminals for temporary storage in large quantities. From here, the product is pumped into tank trucks that deliver it directly to service stations or to larger distributors at "bulk plants." From bulk plants, the product is delivered, again in trucks, to commercial accounts (e.g., trucking companies). The final destination for the gasoline is normally a motor vehicle gas tank. A similar distribution path may be developed for fuel oil and other petroleum products.

4.4.2 Emissions and Controls[2-5]

Losses from marketing and transportation fall into five categories, depending on the storage equipment or mode of conveyance used:

1. Large storage tanks: Breathing, working, and standing storage losses;
2. Railroad tank cars and tank trucks: Loading and unloading losses;
3. Marine vessels: Loading, unloading, and transit losses;
4. Service stations: Loading and unloading losses from tank trucks and underground tanks; and
5. Motor vehicle tanks: Refueling losses.

(In addition, evaporative (and exhaust) emissions are also associated with motor vehicle operation. These topics are discussed in Chapter 3.)

Losses from large storage tanks have been thoroughly discussed in section 4.3.

Unloading losses from tank cars and trucks consist of the amount of organic liquid that evaporates into the air that is drawn in during a complete withdrawal of the contents of a tank compartment. These losses can be estimated (within ± 10 percent) using the following expression derived from American Petroleum Institute correlations:

$$U_t = \frac{69{,}600\ YPW}{(690-4M)T} \quad (1)$$

where: U_t = Unloading loss, lb/10^3 gal of liquid loaded

Y = Degree of saturation of organic in vapor space at time of unloading (estimated or measured)

T = Bulk absolute temperature of organic liquid, °R

P = True vapor pressure of liquid at temperature (T), psia

M = Molecular weight of liquid, lb/lb-mole

W = Density of hydrocarbon liquid at temperature (T), lb/gal

The quantity of loading losses is directly dependent on the filling method used. "Splash" loading, which usually results in extremely high emissions, occurs when the liquid is discharged into the upper part of a container through a short filler spout. This free fall of the liquid encourages both evaporation and entrainment loss caused by the formation and expulsion of liquid droplets. In "subsurface" or "submerged" loading, lower emissions are achieved because the liquid is delivered directly to the bottom of the tank through a tightly connected pipe/spout without splashing.

A submerged loading loss correlation (generally accurate within ± 25 percent) based on equation 1 has also been developed:

$$L_{sub} = \left(\frac{1.00-Y}{2}\right) \frac{69{,}600\ PW}{(690-4M)T} \qquad (2)$$

where: L_{sub} = Submerged loading loss, lb/10^3 gal of liquid loaded

Y = Saturation of the existent vapor in tank before loading.

This relationship assumes that the vapor formed during unloading (existent vapor) remains in the tank until the next loading. Then the additional liquid that evaporates during loading becomes the loading loss. (A more rapid method for calculating loading and unloading losses has been developed by the American Petroleum Institute.[6])

Variables affecting splash loading loss include the loading rate, the degree of saturation of existent vapor, and the elevation and angle of the loading spout. The following correlation was derived from the American Petroleum Institute empirical formula:

$$L_{sp} = \frac{(1.023 \times 10^6)W}{(690-4M)T} \left[\frac{14.7 - YP}{14.7 - (0.95)P} - 1\right] \qquad (3)$$

where: L_{sp} = Splash loading loss, lb/10^3 gal

In equation (3), the vapor displaced from the tank is assumed to be 95 percent saturated—quite reasonable in view of the high degree of saturation observed in vapors from splash-filling operations. The accuracy of this expression is found to be ± 10 percent, 90 percent of the time.

Finally, transit (breathing) losses from tank cars and trucks during product shipment is assumed to be negligible because the travel time is relatively short (2 days or less).

Emission correlations have also been developed for marine vessels.

For unloading losses:

$$U_s = 0.07PW \qquad (4)$$

where: U_s = Unloading loss, lb/10^3 gal of load

P = True vapor pressure of liquid at storage temperature, psia

W = Density of liquid at storage temperature, lb/gal

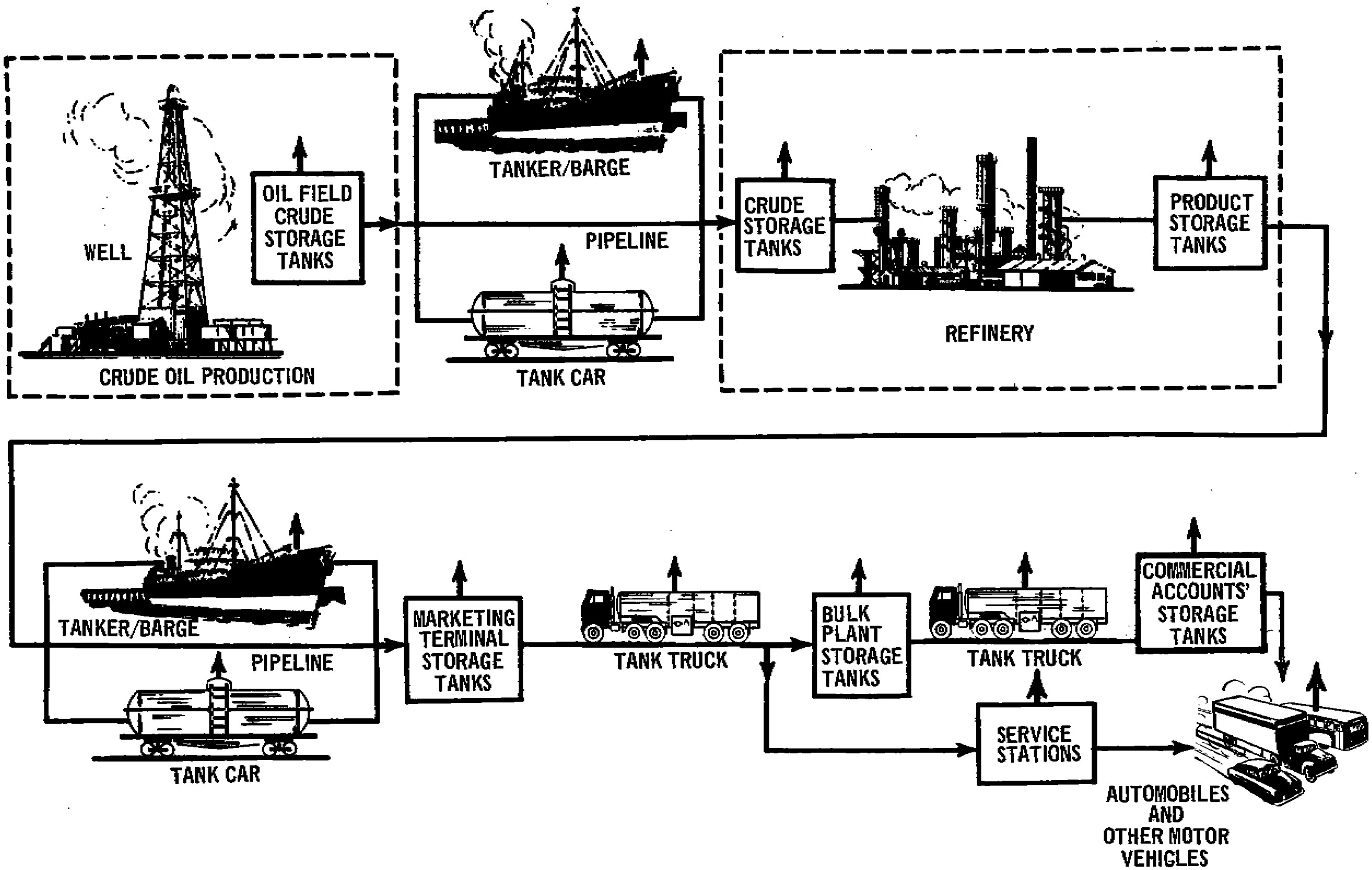

Figure 4.4-1. Flowsheet of petroleum production, refining, and distribution systems. (Sources of organic evaporative emissions are indicated by vertical arrows).

For loading:

$$L_s = 0.08PW \tag{5}$$

where: L_s = Loading loss, lb/10^3 gal of load

Since vessel shipments are transported for longer periods, transit losses can be substantial. These losses can be estimated by the following:

$$R_s = 0.1PW \tag{6}$$

where: R_s = Transit loss, lb/10^3 gal of load per week

For quick reference, selected petroleum product emission factors for transportation sources are provided in Table 4.4-1.

A fourth major source of evaporative emissions is the loading and unloading of underground gasoline storage tanks at service stations. As with the other categories, the quantity of the loading losses depends on several variables such as the size and length of the fill pipe; the method of filling; the tank configuration; as well as the gasoline temperature, vapor pressure, and composition. Depending on these parameters, and the control method used, loading losses can vary from 0 to 11.5 lb/10^3 gal (1.4 kg/10^3 liter) of gasoline pumped into the tank (see Table 4.4-1).

Unloading losses from underground tanks result from the inhalation of air and exhalation of a vapor-air mixture during normal pumping operations. Variables affecting the losses are the type of service station operation, the gasoline pumping rate and frequency, the ratio of liquid surface to vapor volume, the diffusion and mixing of gasoline vapors and air, as well as the other parameters mentioned previously (Table 4.4-1).

The final loss category to be considered is the splash filling of motor vehicle gasoline tanks. These losses consist of vapor displacement (94 percent of total loss) from the vehicle tank and liquid spillage (6 percent of total) as the gasoline is pumped.

Scott Research Inc., under an EPA contract, did extensive laboratory and field testing that resulted in the development of an empirical vapor displacement formula:[5]

$$L_D = 2.22 \exp(-0.02645 + 0.01155T_{DF} - 0.01226T_V + 0.00246T_V P_{RVP}) \tag{7}$$

where: L_D = Vapor displacement loss, lb/10^3 gal

T_{DF} = Average dispensed fuel temperature, °F

T_V = Average temperature of vehicle tank vapor displaced, °F

P_{RVP} = Reid vapor pressure of gasoline pumped, taken at storage temperature and composition, psia

exp = Base of natural logarithms = 2.71828

This expression provides good loss estimates (± 0.5 lb/10^3 gal or 0.06 kg/10^3 liter) within the experimental temperature interval of 30° to 90°F (-1.1° to 32.2 °C).

The quantity of spillage loss is a function of the type of service station, vehicle tank configuration, operator technique, and operation discomfort indices. An overall average of 0.67 lb/10^3 gal (0.081 kg/10^3 liter) has been estimated (Table 4.4-1).

Control methods for transportation and marketing sources are similar to those utilized with large storage tanks and generally consist of one or more types of vapor recovery systems located at transfer terminals. Depending on the system and the compounds recovered, the overall control efficiencies range from 90 to 95 percent.

For example, a technique used with some underground gasoline storage tanks consists of an arrangement by which vapors are recycled to the tank trucks during filling operations through the annular space of a specially designed "interlock valve" and into a side arm that is connected to the return manifold in the dome cap of the truck (see Figure 4.4-2). The control efficiency of this method ranges from 93 to 100 percent when compared with uncontrolled, splash-fill loading (see Table 4.4-1).

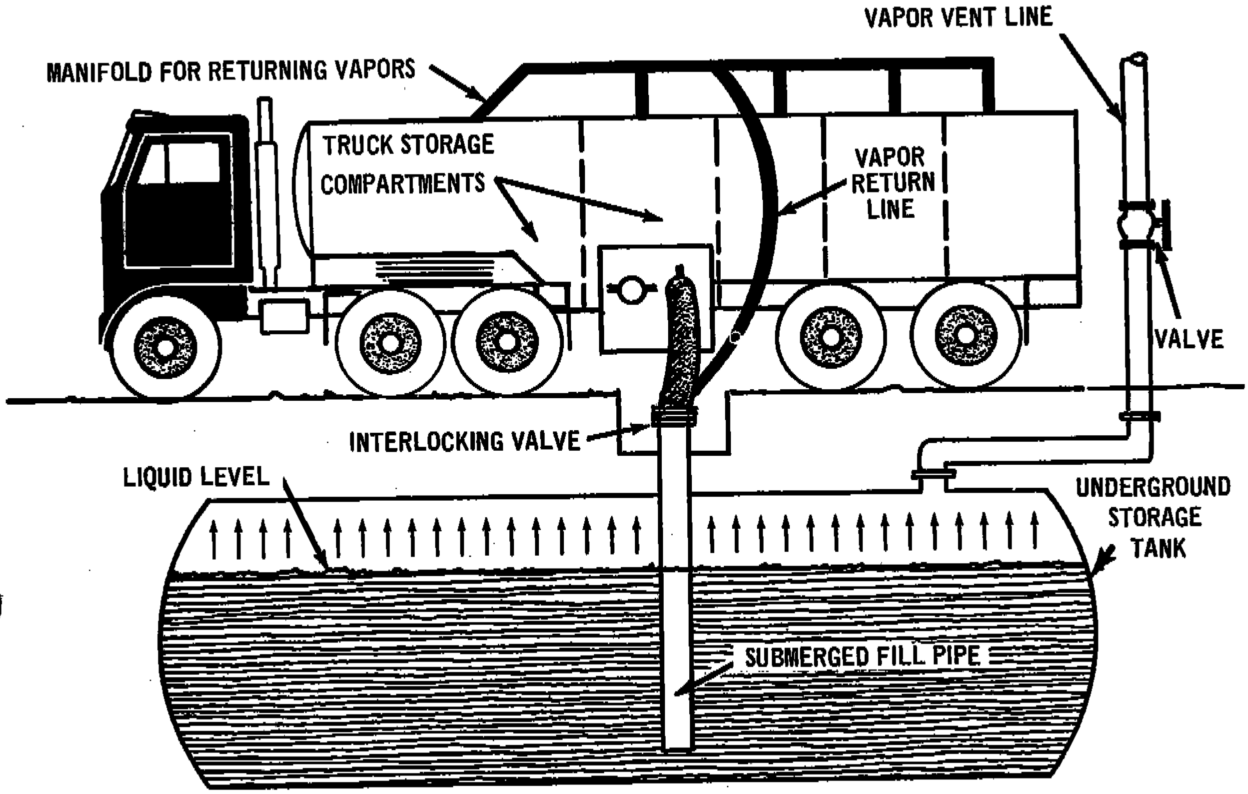

Figure 4.4-2. Underground storage tank vapor-recovery system[1].

Table 4.4-1. ORGANIC COMPOUND EVAPORATIVE EMISSION FACTORS FOR PETROLEUM TRANSPORTATION AND MARKETING SOURCES[a]
EMISSION FACTOR RATING: A

Emission source	Product				
	Gasoline	Crude oil	Naphtha jet fuel (JP-4)	Kerosene	Distillate oil
Tank cars/trucks[b]					
Splash loading					
lb/10^3 gal transferred	12.4	10.6	1.8	0.88	0.93
kg/10^3 liter transferred	1.5	1.3	0.22	0.11	0.11
Submerged loading					
lb/10^3 gal transferred	4.1	4.0	0.91	0.45	0.48
kg/10^3 liter transferred	0.49	0.48	0.11	0.054	0.058
Unloading					
lb/10^3 gal transferred	2.1	2.0	0.45	0.23	0.24
kg/10^3 liter transferred	0.25	0.24	0.054	0.028	0.029
Marine vessels[b]					
Loading					
lb/10^3 gal transferred	2.9	2.6	0.60	0.27	0.29
kg/10^3 liter transferred	0.35	0.31	0.072	0.032	0.035
Unloading					
lb/10^3 gal transferred	2.5	2.3	0.52	0.24	0.25
kg/10^3 liter transferred	0.30	0.28	0.062	0.029	0.030
Transit					
lb/wk-10^3 gal load	3.6	3.2	0.74	0.34	0.36
kg/wk-10^3 liter load	0.43	0.38	0.089	0.041	0.043
Underground gasoline storage tanks[c]					
Splash loading					
lb/10^3 gal transferred	11.5	NU[d]	NU	NU	NU
kg/10^3 liter transferred	1.4	NU	NU	NU	NU
Uncontrolled submerged loading					
lb/10^3 gal transferred	7.3	NU	NU	NU	NU
kg/10^3 liter transferred	0.38	NU	NU	NU	NU
Submerged loading with open vapor return system					
lb/10^3 gal transferred	0.80	NU	NU	NU	NU
kg/10^3 liter transferred	0.097	NU	NU	NU	NU
Submerged loading with closed vapor return system					
lb/10^3 gal transferred	Neg	NU	NU	NU	NU
kg/10^3 liter transferred	Neg	NU	NU	NU	NU

Table 4.4-1 (continued). ORGANIC COMPOUND EVAPORATIVE EMISSION FACTORS FOR PETROLEUM TRANSPORTATION AND MARKETING SOURCES
EMISSION FACTOR RATING: A

Emission source	Product				
	Gasoline	Crude oil	Naphtha jet fuel (JP-4)	Kerosene	Distillate Oil
Unloading					
lb/10^3 gal transferred	1.0	NU	NU	NU	NU
kg/10^3 liter transferred	0.12	NU	NU	NU	NU
Filling motor vehicle gasoline tanks[e]					
Vapor displacement loss					
lb/10^3 gal pumped	11.0	NU	NU	NU	NU
kg/10^3 liter pumped	1.3	NU	NU	NU	NU
Liquid spillage loss					
lb/10^3 gal pumped	0.67	NU	NU	NU	NU
kg/10^3 liter pumped	0.081	NU	NU	NU	NU

[a]References 1, 3, and 5.
[b]Data based on the following conditions:

Storage temperature: 63 °F (17.2 °C)
Saturation of tank existent vapors in loading and unloading tank trucks and cars: 20 percent

	Gasoline	Crude oil	Naphtha jet fuel (JP-4)	Kerosene	Distillate oil
Molecular weight of vapor, lb/lb-mole	56.8	64.5	63.3	72.7	72.7
Reid vapor pressure					
psia	10.5	7.0	2.5	0.5	0.5
Mg/m²	7.4	4.9	1.75	0.35	0.35
True vapor pressure					
psia	5.8	4.6	1.2	0.5	0.5
Mg/m²	4.1	3.2	0.84	0.35	0.35
Liquid density					
lb/gal	6.2	7.0	6.2	6.8	7.2
kg/liter	0.74	0.84	0.74	0.82	0.87

[c]Factors for underground gasoline storage tanks based on an organic compound vapor space concentration of 40 percent by volume, which corresponds to a saturation of nearly 100 percent.
[d]Not used.
[e]Motor vehicle gasoline tank vapor displacement factor based on an average dispensed fuel temperature of 63 °F (17.2 °C), an average displaced vapor temperature of 67 °F (19.4 °C), and a Reid vapor pressure of 10.5 psia (7.4 Mg/m²).

REFERENCES FOR SECTION 4.4

1. Nichols, Dr. Richard A. Control of Evaporation Losses in Gasoline Marketing Operation. (Presented at the Technical Conference on New Technology in the Solution of Practical Problems in Air and Water Pollution Control. Tokyo, Japan. December 1971).

2. Chass, R.L. et al. Emissions from Underground Gasoline Storage Tanks. J. Air Pol. Control Assoc. 13:524-530, November 1963.

3. Evaporation Loss from Tank Cars, Tank Trucks, and Marine Vessels. American Petroleum Institute, New York, N.Y. API Bulletin Number 2514. November 1959.

4. Petrochemical Evaporation Loss from Storage Tanks. American Petroleum Institute, New York, N.Y. API Bulletin Number 2523. November 1969.

5. Smith, Malcolm. Investigation of Passenger Car Refueling Losses. Scott Research Laboratories, Inc. San Bernadino, Calif. Prepared for Mobile Source Pollution Control Program, Office of Air and Water Programs, EPA, Ann Arbor, Mich. under Contract Number CPA 22-69-68. September 1972.

6. American Petroleum Institute, New York, N.Y. API Bulletin Number 4080. July 1971.