

Manual of Petroleum Measurement Standards Chapter 19.5

Atmospheric Hydrocarbon Emissions from Marine Vessel and Land Based Transfer Operations

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Atmospheric Hydrocarbon Emissions from Marine Vessel and Land Based Transfer Operations

1 Scope

This standard provides methods for estimating evaporative loss from marine vessel and land based transfer operations. Specifically, this standard addresses:

1) loading stock into:

ship or ocean barges, or shallow draft barges,
tank trucks, and
rail cars.

loading ballast water into ship or ocean barges from which crude oil has been unloaded.

This standard does not address evaporative loss for:

- 1) very large crude carriers (VLCCs) or ultra large crude carriers (ULCCs) (unless the saturation factor KS is determined—note that the saturation factors given in this standard for ships would be expected to be conservative for cargo compartment depths greater than 40 ft);
- 2) marine vessels employing crude oil washing (see 3.1.5);
- 3) marine vessel transit loss;
- 4) loading ballast water into marine vessels that, prior to dockside unloading, held anything other than crude oil (unless the saturation factor KS is determined); or
- 5) unloading marine vessels.

2 Normative References

There are no documents referred to in the text in such a way that some or all of their content constitutes requirements of this document.

3 Terms, Definitions, and Symbols

3.1 For the purposes of this document, the following terms and definitions apply.

3.1.1

ballasted compartment

An uncleaned compartment that has been loaded with ballast water.

3.1.2

capture efficiency

The percent of vapors displaced from a cargo compartment during loading that are routed into the terminal's vapor collection system.

3.1.3

cleaned compartment

A compartment that has been water washed.

3.1.4**control device efficiency**

The percent of vapors routed through the terminal's vapor collection system to the vapor control device that are destroyed or removed by the vapor control device.

3.1.5**crude oil washing**

The use of a high pressure stream of crude oil or cutter stock, usually heated, to dislodge or dissolve clingage and sediments from bulkheads, compartment bottoms, and internal structures of a vessel during the discharge operation. ^[7]

3.1.6**dedicated normal service**

A compartment designated to transport only one product. ^[8]

3.1.7**dedicated vapor balance service**

A compartment designated to transport only one product, and which retrieves the vapors displaced during product unloading at bulk plants or service stations and transports the vapors back to the loading terminal. ^[8]

3.1.8**fully-loaded compartment**

A compartment with a true ullage height of 5 ft or less prior to dockside crude oil unloading.

3.1.9**gas-freed compartment**

A compartment that has been cleaned and air-blown, such that the compartment is suitable for entry and hot work such as welding.

3.1.10**lightered**

Partially unloaded before reaching the dock.

3.1.11**lightered or previously short-loaded compartment**

A compartment with a true ullage of more than 5 ft prior to dockside crude oil unloading.

3.1.12**nonvolatile cargo**

Cargo with a true vapor pressure of 1.5 psia or less. Nonvolatile cargo includes fuel oils such as No. 2 fuel oil (diesel) and No. 6 fuel oil.

NOTE See API *MPMS* Chapter 19.4 for determination of true vapor pressure.

3.1.13**shallow draft barge**

Marine vessels with compartment depths of ~10 ft to 12 ft.

3.1.14**ship or ocean barge**

See 3.1.11.

3.1.15**splash loading**

In the splash loading method, the fill pipe dispensing the cargo is lowered only part way into the cargo compartment. ^[9]

3.1.16**submerged loading**

The types of submerged loading are the submerged fill pipe method and the bottom loading method. During most of submerged loading by both methods, the fill pipe opening is below the liquid surface level. ^[8]

3.1.17**ullage**

The unfilled volume of a compartment.

3.1.18**uncleaned compartment**

A compartment that has had no treatment except routine heel washing (washing restricted to the lower part of the compartment).

3.1.19**volatile cargo**

Cargo with a true vapor pressure greater than 1.5 psia.

NOTE API MPMS Chapter 19.4 for determination of true vapor pressure.

4 Procedures for Estimating Loss

This section summarizes estimating loading and disconnect losses. Loading losses involve vapors displaced from a cargo compartment during a loading operation. The loading operation may be uncontrolled as described in [4.1](#) and [4.2](#) or controlled as described in [4.3](#). The conceptual framework for calculating loading losses is to calculate the mass of saturated vapor that would be displaced by the volume of liquid loaded, and multiply by a saturation factor; further information on the development of the loading loss method is provided in [Section 6](#). Disconnect losses involve vapor or liquid escaping from the loading arm or hose upon disconnect from the cargo compartment as described in [4.4](#). Disconnect losses may occur regardless of whether loading losses are controlled or uncontrolled.

4.1 Uncontrolled Loading Loss

As detailed in [Section 6](#), the vapor loss from a cargo compartment during an uncontrolled petroleum liquid loading episode is:

$$L_{LT} = V_L K_S P_{VA} M_V / (RT_V) \quad (1)$$

where

L_{LT}	is the total vapor loss for the loading event
V_L	is the volume of liquid loaded;
K_S	is the saturation factor (see Table 2 and Table 3);
P_{VA}	is the true vapor pressure of the liquid;
M_V	is the molecular weight of the stock vapors;
R	is the ideal gas constant;
T_V	is the absolute temperature of the ullage.

This equation can be written as (with the units as given in [Table 1](#)):

$$L_L \text{ lb/(1000 gal loaded)} = 12.46 K_S P_{VA} M_V / T_V \quad (2)$$

or

$$LL \text{ kg}/(1000 \text{ l loaded}) = 0.1203 K_s P_{VA} M_V/T_V \quad (3)$$

[Table 2](#) shows that the loading loss saturation factor for marine vessels is a function of the compartment condition prior to loading. A marine vessel can have more than one compartment and the compartments can have different conditions prior to loading. As indicated above, details on determination of saturation factors are included in [Section 6](#).

Table 1—Nomenclature

Symbol	USC Units	SI Units	Description
CE	percent	percent	capture efficiency
E_L	—	—	dimensionless
K_s	—	—	saturation factor
L_L	lb/(1000 gal loaded)	kg/(1000 l loaded)	loading loss per volume loaded
L_{LT}	lb	kg	total loading loss for a loading event
M_V	lb/lb-mole	kg/kg-mole	molecular weight of the stock vapors (see API MPMS Chapter 19.4 [1], Table 2)
P_{VA}	lb/in. ²	kPa	true vapor pressure of the liquid (see API MPMS Chapter 19.4 [1])
R	lb-ft ³ /(lb-mole °R-in. ²)	l-atm/(g-mole K)	ideal gas constant = 10.731 lb-ft ³ /(lb-mole °R-in. ²) ideal gas constant = 0.08206 l-atm/(g-mole K)
T_V	°R	K	best estimate of absolute temperature of the ullage
V_L	ft ³ , gal, or bbl	m ³ or l	volume of liquid loaded
CDE	percent	percent	destruction/removal efficiency of vapor control device
W_V	lb/ft ³	kg/m ³	density of the stock vapors

Table 2—Marine Vessel Loading Loss Saturation Factor K_s

Marine Vessel Type	Prior Cargo	Compartment Condition Prior to Loading	K_s (Gasoline Loading)	K_s (Crude Oil Loading)	K_s (Other Petroleum Liquids Loading)
Ship or ocean barge	Volatile	Uncleaned	0.2	0.2	0.2
Ship or ocean barge	Volatile	Ballasted	0.15	0.15	—
Ship or ocean barge	Volatile	Cleaned	0.10	0.10	—
Ship or ocean barge	Volatile	Gas freed	0.10	0.10	—
Ship or ocean barge	Nonvolatile	Uncleaned, ballasted, cleaned, or gas freed	0.10	0.10	—
Shallow draft barge	Volatile	Uncleaned	0.3	0.3	0.5
Shallow draft barge	Volatile	Cleaned or gas freed	0.15	—	—
Shallow draft barge	Nonvolatile	Uncleaned, cleaned, or gas freed	0.15	—	—

[Table 3](#) shows the loading loss saturation factor for tank trucks and rail cars as a function of the mode of operation.

Table 3—Tank Truck and Rail Car Loading Loss Saturation Factor K_s

Cargo Compartment Condition	Type of Loading	K_s
Clean	Submerged loading	0.50
Dedicated normal service	Submerged loading	0.60
Dedicated vapor balance service	Submerged loading	1.00
Clean	Splash loading	1.45
Dedicated normal service	Splash loading	1.45
Dedicated vapor balance service	Splash loading	1.00
NOTE References [8] and [14].		

4.2 Uncontrolled Ballasting Loss

While this section addresses the introduction of ballast water into cargo compartments, ballasting of ships now typically involves segregated ballast tanks that would avoid ballasting losses. The total vapor loss for an episode of uncontrolled ballast water loading into a cargo compartment L_{LT} is the same as for petroleum liquid loading, but with the variables as defined below:

$$L_{LT} = V_L K_s P_{va} M_v / (R T_v) \quad (1)$$

where

- V_L is the volume of the ballast water loaded into compartments that previously contained crude oil. If the volume is unknown, it may be estimated as 17 % of the volume of the crude oil unloaded;
- K_s is the saturation factor (see [Table 4](#));
- P_{va} is the true vapor pressure of the crude oil unloaded;
- M_v is the vapor molecular weight of the crude oil unloaded;
- R is the ideal gas constant;
- T_v is the absolute temperature of the ullage.

This equation can be written as:

$$L_L \text{ lb}/(1000 \text{ gal loaded}) = 12.46 K_s P_{va} M_v / T_v \quad (2)$$

or

$$LL \text{ kg}/(1000 \text{ l loaded}) = 0.1203 K_s P_{va} M_v / T_v \quad (3)$$

Like [Table 2](#), [Table 4](#) shows that the ballasting loss saturation factor is a function of the compartment condition prior to loading. A barge can have more than one compartment and the compartments can have different conditions prior to loading. As indicated above, details on documentation are included in [6.4](#).

Table 4—Ballasting Loss Saturation Factor K_s

Marine Vessel Type	Prior Cargo	Compartment Condition Prior to Dockside Crude Oil Unloading	K_s
Ship or ocean barge	Crude oil	Fully loaded	0.20
Ship or ocean barge	Crude oil	Lightered or previously short loaded	0.35

4.3 Controlled Loading Loss

The procedures discussed above are used to calculate uncontrolled emissions from loading operations. When emissions from loading operations are controlled by routing vapors displaced from the cargo compartment through a vapor collection system to a vapor control device, there are three potential mechanisms for a portion of the vapors to be released to atmosphere.

As vapors are displaced by the rising liquid level in the cargo compartment, some vapors can leak from the cargo compartment to atmosphere rather than being routed to the terminal's vapor collection system. These emissions are addressed as capture efficiency in [4.3.1](#).

Some vapors may leak from the terminal's vapor collection system prior to arrival at the vapor control device. Leakage from the terminal's vapor collection system is typically accounted for as equipment leaks in the same manner as for other piping components and is thus not included in the estimation of loading losses and is not addressed in this document.

The vapor control device is typically not 100 % effective in recovering or destroying the vapors, and thus some vapors can be vented from the vapor control device to atmosphere. These emissions are addressed as control device efficiency in [4.3.2](#).

Losses from controlled loading may be estimated by applying the overall control efficiency to the estimated uncontrolled emissions. The overall control efficiency for loading operations is therefore calculated as the product of the capture efficiency and the control device efficiency and the total loading loss for a controlled loading operation may be expressed as shown below.

$$L_{LT} = [1 - (CE/100)(CDE/100)] V_L K_S P_{VA} M_V / (RT_V) \quad (4)$$

where

CE is the capture efficiency (percent); and
 CDE is the control device efficiency (percent).

4.3.1 Capture Efficiency

The effectiveness at which vapors are routed from the cargo compartment being loaded into the terminal's vapor collection system, rather than leaking directly to atmosphere, is referred to as the capture efficiency. For example, a capture efficiency of 99 % means that 99 % of the vapors are routed to the terminal's vapor collection system and 1 % are leaked to atmosphere. The capture efficiency is a function of the vapor-tightness of the cargo compartment.

When the mechanism for expelling vapors from the cargo compartment is the pressure increase resulting from the liquid level in the compartment rising during loading, then the positive pressure in the cargo compartment can result in some vapors leaking to atmosphere through fittings such as a pressure-relief vent or a hatch. However, when the mechanism for expelling vapors involves a vacuum assist system that maintains a vacuum in the headspace of the cargo compartment, then it may be assumed there is no leakage to atmosphere from the cargo compartment and 100 % of the vapors are drawn into the terminal's vapor collection system. Vapor collection systems commonly maintain a vacuum in the vapor collection header, but do not necessarily maintain a vacuum in the cargo compartment. Ships and ocean barges are generally required to maintain an inert atmosphere in the cargo compartment for safety purposes and do so by maintaining positive pressure in the cargo compartment.

[Table 5](#) shows capture efficiencies corresponding to various standards of vapor-tightness.

Table 5—Capture Efficiency, *CE*

Type of Vehicle or Vessel	Vapor-tightness Standard	CE	Note
All types	Vacuum assist	100 %	1
Liquefied compressed gas tank truck or rail car	DOT certification	100 %	2
Ship or ocean barge	Subject to annual pressure-drop testing and leak monitoring during loading	99.9 %	3
Ship or ocean barge	Subject to annual pressure-drop testing	99 %	4
Tank truck or rail car	1-in. pressure-drop limit	99.2 %	5
Tank truck or rail car	3-in. pressure-drop limit	98.7 %	5
Tank truck or rail car	Not subject to annual pressure-drop testing	70 %	6
Ship or ocean barge	Not subject to annual pressure-drop testing or monitoring	65 %	7

NOTE 1 This applies to vacuum-assisted loading where the cargo compartment headspace is maintained at a partial vacuum. It does not apply to systems that maintain a partial vacuum in the vapor collection header but not in the vessel cargo compartment. Shallow draft barge loading is often equipped with vacuum assist, but ships and ocean barges are generally required to maintain an inert atmosphere in the cargo compartment for safety purposes and thus are precluded from the use of vacuum assist.

NOTE 2 Tank trucks and rail cars designed to transport liquefied compressed gases may be assumed to have no leakage during loading if certified under a standard applicable to pressurized cargo, such as DOT MC 3311 (49 CFR 178.337) for tank trucks or DOT 105 (49 CFR 179 Subpart C) for rail cars. There may be emissions, however, from the disconnecting of loading hoses as addressed in [4.4](#).

NOTE 3 See [Annex G](#) and Reference [16].

NOTE 4 See [Annex G](#) and Reference [15].

NOTE 5 See [6.5](#).

NOTE 6 Reference [8].

NOTE 7 Reference [13].

4.3.2 Control Device Efficiency

Control of loading emissions involves routing the vapors to a control device. The control efficiency of a control device is typically determined by testing of the device or by design information provided by the manufacturer. In such cases, the control device efficiency can be determined directly from this information.

Emission rates for a control device are sometimes expressed in terms of milligrams of vapor vented from the control device per liter of liquid loaded into the cargo compartment (mg/l). In loading involving cargo compartments that are in dedicated vapor balance service, an emission rate in terms of (mg/l) may be converted to a control device efficiency by assuming the air displaced from the cargo compartment to be saturated with vapors. The saturated vapor density W_v may be calculated from the following equation.

$$W_v = \frac{M_v P_{VA}}{R T_v} \quad (5)$$

where

- W_v = density of stock vapors,
- M_v = the molecular weight of the stock vapors,
- P_{VA} = the true vapor pressure of the stock,
- R = the ideal gas constant, and
- T_v = the absolute temperature of the stock vapors.

In the absence of site-specific data, the following values may be assigned to determine a representative saturated vapor density for gasoline:

- M_v 66 lb/lb-mole;
- P_{VA} 5.2 psia (for RVP 10 gasoline at 60 °F);
- R 10.731 lb-ft³/(lb-mole °R-in.²);
- T_v 520 °R (60 °F).

The resulting vapor density is 0.062 lb/ft³, or ~1,000 mg/l. An emission rate for gasoline given in terms of (mg/l) may then be converted to a control device efficiency as follows:

$$CDE = \left(1 - \frac{\text{emission rate (mg/l)}}{1000 \text{ (mg/l)}} \right) 100 \quad (6)$$

For example, an emission rate of 10 mg/l would correspond to a control device efficiency of 99 %.

4.4 Disconnect Losses

In certain scenarios vapor or liquid can be released from the loading arm or hose upon disconnect from the cargo compartment. Disconnect losses are often a small percentage of a facility's overall emissions; however, for completeness, emission estimate calculations for disconnect losses are described in this section. When the hose or piping used to load a cargo compartment is disconnected, the portion of the line between the cutoff valve and the end of the line is opened to the atmosphere. Loading arms for petroleum liquids typically have a coupling at the end of the line, deemed a dry-disconnect or dry-break coupling, that is intended to limit leakage to a few drops. In the event that the disconnect involves a length of loading arm or hose being opened to the atmosphere, however, emissions may be estimated as the product of the volume of the open line times the density of the gas or liquid released from the line using the equation below.

$$L_d = V_d(W_v \text{ or } W_L) \quad (7)$$

where

- L_d is the loss per disconnect event;
- V_d is the volume of open hose, accounting for both the loading arm and cargo compartment sides;
- W_v or W_L is the density of the gas or liquid released.

In the absence of case-specific information, it may be assumed that loading of liquified gas into tank trucks involves 18 in. of 2-in. line being opened upon disconnecting the loading hose from the liquified gas cargo compartment. The following values may be assumed for the density of pure liquified gases as indicated in API MPMS Chapter 19.4:

Butane—4.8 lb/gal (570 kg/m³)

Propane—4.1 lb/gal (490 kg/m³)

Propylene—4.2 lb/gal (510 kg/m³)

5 Sample Problems

5.1 Loss from Loading Gasoline

5.1.1 Parameters

Marine vessel—ocean barge.

Prior cargo—volatile.

Compartment conditions prior to loading: 25 % uncleaned, 10 % ballasted; 65 % gas freed.

Temperature of the ullage—60 °F = 520 °R.

Gasoline—RVP 13 (from API *MPMS* Chapter 19.4, [Table 2](#), $P_{VA} = 7.0$ at 60 °F and $MV = 62$ lb/lb-mole).

Volume loaded—125,000 bbl.

5.1.2 Solution

The volume loaded is 125,000 bbl (42 gal/bbl) = 5,250,000 gal.

The average saturation factor for the compartments is (see [Table 2](#)):

$$K_s = 0.25(0.20) + 0.10(0.15) + 0.65(0.10) = 0.13$$

The loss from loading gasoline from Equation (2) is:

$$L_L \text{ lb/(1000 gal loaded)} = 12.46 K_s P_{VA} M_V / T_V$$

$$L_L \text{ lb/(1000 gal loaded)} = (12.46)(0.13)(7.0)(62)/(520) = 1.35 \text{ lb/(1000 gal loaded)}$$

and the total loss is:

$$L_{LT} = 1.35 \text{ lb}(5,250,000/1000) = 7100 \text{ lb}$$

5.2 Loss from Loading Crude Oil

5.2.1 Parameters

Marine vessel—ship.

Prior cargo—crude oil.

Compartment conditions prior to loading—85 % uncleaned, 15 % cleaned.

Temperature of the ullage—60 °F = 520 °R.

Crude oil— $P_{VA} = 2.0$ at 60 °F (from API *MPMS* Chapter 19.4, [Table 2](#), $M_V = 50$ lb/lb-mole).

Volume loaded—180,000 bbl.

5.2.2 Solution

The volume loaded is 180,000 bbl (42 gal/bbl) = 7,560,000 gal.

The average saturation factor for the compartments is (see [Table 2](#); the previous cargo was crude oil, which is considered volatile per the definition given in 3.1.19):

$$K_s = 0.85(0.20) + 0.15(0.10) = 0.185$$

The loss from loading crude oil from Equation (2) is:

$$L_L \text{ lb}/(1000 \text{ gal loaded}) = 12.46 K_s P_{VA} M_V/T_V$$

$$L_L \text{ lb}/(1000 \text{ gal loaded}) = 12.46 (0.185)(2.0)(50)/(520) = 0.443 \text{ lb}/(1000 \text{ gal loaded})$$

and the total loss is:

$$L_{LT} = (0.443 \text{ lb})(7,560,000/1000) = 3350 \text{ lb}$$

5.3 Loss from Loading Ballast Water

5.3.1 Parameters

Marine vessel—ocean barge.

Prior cargo—crude oil.

Compartment conditions prior to loading ballast water: 80 % had been loaded to 1 ft ullage, 20 % had been lightered to 10 ft ullage.

Temperature of the ullage: 70 °F = 530 °R.

Crude oil— $P_{VA} = 3.8$ at 70 °F (from API *MPMS* Chapter 19.4, [Table 2](#), $M_V = 50$ lb/lb-mole).

Volume unloaded: 600,000 bbl of crude oil; 17 % of the volume is filled with ballast water after unloading the crude oil.

5.3.2 Solution

The volume of ballast water loaded is 0.17(600,000 bbl)(42 gal/bbl) = 4,284,000 gal.

The average saturation factor for the compartments is (see [Table 4](#)):

$$K_s = 0.80(0.20) + 0.20(0.35) = 0.23$$

The loss from loading ballast water from Equation (2) is:

$$L_L \text{ lb}/(1000 \text{ gal loaded}) = 12.46 K_s P_{VA} M_V/T_V$$

$$L_L \text{ lb}/(1000 \text{ gal loaded}) = 12.46(0.23)(3.8)(50)/(530) = 1.03 \text{ lb}/(1000 \text{ gal loaded})$$

and the total loss is:

$$L_{LT} = 1.03 \text{ lb}(4,284,000/1000) = 4400 \text{ lb}$$

5.4 Loss from Controlled Loading of Crude Oil or Gasoline

5.4.1 Parameters

Marine vessel—ship or ocean barge.

Prior cargo—crude oil or gasoline

Uncontrolled Loading Loss $L_L = 7100$ lb

Capture efficiency— $CE = 99\%$

Control device efficiency— $CDE = 99.9\%$

5.4.2 Solution

Calculate the controlled loading losses by applying the capture and control device efficiencies to the calculated loading loss:

$$L_{LT} = [1 - (99/100)(99.9/100)] 7100 \text{ lb}$$

$$L_{LT} = [1 - 0.98901] 7100 \text{ lb}$$

$$L_{LT} = 78 \text{ lb}$$

6 Development of the Equations for Estimating Loss

6.1 General Expression for Loading Loss

The general expression for loading loss shown in Equation (1) is based on the ideal gas law as described in this section. The values shown in [Table 2](#) for the saturation factor K_s are based on solving Equation (2) for K_s from the values given for the loading loss L_{LT} in a previous edition of this document ^[3] (i.e. the saturation factors were simply back-calculated from the earlier emission factors).

Loading loss can be determined using the general expression:

$$(\text{loading loss}) = (\text{volume loaded})(\text{a saturation factor})(\text{ideal vapor density at equilibrium})$$

The ideal vapor density at equilibrium may be derived as follows:

$$\text{density} = (\text{mass})/(\text{volume})$$

$$\text{mass} = (\text{number of moles, } n)(\text{molecular weight of the vapors, } M_v)$$

The density of the vapors W_v for a volume V_L is therefore:

$$W_v = (n M_v)/V_L, \text{ and at equilibrium, the ideal gas law states:}$$

$$n/V_L = P_{vA}/(RT_v)$$

Combining these equations:

$$W_v = (P_{vA} \cdot M_v)/(RT_v)$$

where

- W_v is the density of the stock vapors;
 P_{VA} is the true vapor pressure of the stock liquid being loaded;
 P_{VA} is the molecular weight of the stock vapors;
 R is the ideal gas constant;
 T_v is the absolute temperature of the ullage.

The mass of vapors at ideal equilibrium conditions in a volume V_L may therefore be expressed as:

$$(\text{mass of vapors}) = (\text{volume})(\text{density})$$

$$(\text{mass of vapors}) = V_L (P_{VA} M_v) / (R T_v)$$

The vapors of petroleum stocks are typically heavier than air, however. Gravity causes these vapors to settle toward the bottom of a given space. This gravity action results in the vapor density at the higher portions of the vapor space being less than that predicted for equilibrium conditions by the ideal gas law. The extent to which the vapor concentration is less than the ideal equilibrium concentration may be expressed as a saturation factor K_s .

The quantity of vapors L_{LT} that are lost (displaced) during a given loading event may therefore be expressed as follows:

$$L_{LT} = V_L K_s P_{VA} M_v / (R T_v) \quad (1)$$

Substituting 10.731 (psia ft³)/(lb-mole °R) for the ideal gas constant R and 1000 gal for the volume V_L , and including a conversion factor of 7.48 gal/ft³, this equation becomes:

$$L_L \text{ lb}/(1000 \text{ gal loaded}) = 12.46 K_s P_{VA} M_v / T_v \quad (2)$$

The loading loss consists of two components: loss of vapors resident in the vapor space from the prior cargo, and loss of vapors generated during loading of the new cargo. If the prior cargo and the new cargo are P_{VA} different, a more precise loss estimate might be determined by using their respective vapor pressures and vapor molecular weights for separate resident and generated loss estimates.

6.2 Saturation Factors for Loading Gasoline

The gasoline loading saturation factors of [Table 6](#) were developed from [Table A.1](#), which is based on data for which was 8 psia (see [F.1.1](#)) and a typical vapor molecular weight M_v of 64 lb/lb-mole was assumed (see [B.3](#)). Assuming a temperature T_v of 523 °R (63 °F) (a reasonable annual average temperature in the continental United States, and consistent with what had been used in API *MPMS* Chapter 19.1 ^[10] for filling fixed roof tanks) and substituting these values into Equation (2):

$$LL \text{ lb}/(1000 \text{ gal loaded}) = 12.46 K_s (8 \text{ psia})(64 \text{ lb/lb-mole})/(523 \text{ °R})$$

$$LL \text{ lb}/(1000 \text{ gal loaded}) = 12.2 K_s$$

[Table A.1](#) provides the gasoline loading loss LL for various vessels, prior cargos, and compartment treatments during the ballast voyage. These were used to determine the saturation factor K_s given in [Table 2](#) for these

various conditions. For example ¹, for a barge whose prior cargo was volatile and whose compartment was uncleaned prior to loading, the saturation factor K_s for gasoline loading is calculated as:

$3.9 = 12.2 K_s$, so $K_s = 3.9/12.2 = 0.32$, which is rounded to 0.3 in [Table 2](#)

The emission factors from [Table A.1](#) and the corresponding saturation factors, where $K_s = L_L/12.2$, are summarized as follows. The saturation factors in [Table 2](#) were rounded to the nearest 0.05. In [Table 2](#), saturation factors for loading other petroleum liquids were taken from AP-42 ^[8], Table 5.2-1.

Table 6—Saturation Factors for Gasoline Loading

Category	Vessel	Prior Cargo	Compartment Treatment During Ballast Voyage	Average Emission Factor (lb/1000 gal loaded) L_L	Saturation Factor $K_s = L_L/12.2$
1	Tanker/ocean barge	Volatile	Uncleaned	2.6	0.21
2	Tanker/ocean barge	Volatile	Ballasted	1.7	0.14
3	Tanker/ocean barge	Volatile	Cleaned	1.5	0.12
4	Tanker/ocean barge	Volatile	Gas freed	0.7	0.06
		Nonvolatile	Ballasted, cleaned, gas freed, uncleaned		
5	Barge	Volatile	Uncleaned	3.9	0.32
6	Barge	Volatile	Cleaned, gas freed	2.0	0.16
		Nonvolatile	Uncleaned, cleaned, gas freed		

API 2524 ^[2] reports data from 19 tests of gasoline loading into uncleaned barge compartments, with true vapor pressure reported for three of these tests. A comparison of the measured emissions to the emissions predicted is given as follows.

[Table 7](#) shows that the API *MPMS* Chapter 19.5 loss estimates are closer than the API 2514A-1981 ^[3] loss estimates to the measured loss reported in API 2524.

Table 7—API 2524 Loss Data Compared with Predicted Loss

Test	Volume Loaded (bbl)	Volume Loaded (ft ³)	P_{VA} (psia)	Measured Loss (lb/103 gal)	<i>MPMS</i> Chapter 19.5 Loss ^a (lb/103 gal)	API 2514A-1981 Loss (lb/103 gal)
121	2392	13,431	7.1	2.29	3.2	3.9
122	2404	13,498	7.1	2.18	3.2	3.9
123	2437	13,684	7.1	2.09	3.2	3.9
^a Equation (2) with $K_s = 0.3$.						

¹ The following examples are merely for illustration purposes only. Each company should develop its own approach. They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

Additional data are available from tests reported by Spectrasyne ^[4] and CONCAWE ^[5]. The objective of these tests was to use DIAL infrared technology to measure emissions from storage tanks, but these studies first measured emissions from barge loading to establish a correlation with DIAL measurements of the emissions plume. (DIAL is an acronym for differential absorption LIDAR, and LIDAR is an acronym for light detection and ranging—a light-based range finding system similar to RADAR, using a laser as the light source.)

Barge loading was used to establish a correlation with DIAL measurements because the venting of barge loading emissions through a single stack allowed them to be directly measured for comparison with the downwind DIAL readings. The results of the vent measurements are summarized in [Table 8](#) and compared with estimated values. The molecular weight of the stock vapor, M_v , was reported as 69 lb/lb-mole, but the true vapor pressure was not given. The emission estimates using Equation (2) are calculated at true vapor pressures of both 7 psia and 8 psia, to illustrate a range of likely results. In each case, the value for the saturation factor used in Equation (2) is 0.3.

Again, while the API 2514A-1981 loss factor gives a reasonable prediction of emissions, some improvement may be achieved by using Equation (2) with a saturation factor of 0.3 from this standard (API MPMS Chapter 19.5).

Table 8—CONCAWE Loss Data Compared with Predicted Loss

Test Set	Measured Emissions (kg)	Volume Loaded (m ³)	Measured Rate (kg/m ³)	Measured Rate (lb/Mgal)	API MPMS Ch. 19.5 ^a P = 7 psia (lb/Mgal)	API MPMS Ch. 19.5 ^a P = 8 psia (lb/Mgal)	API 2514A-1981 Loss (lb/Mgal)
Reference [4]	390	950	0.411	3.4	3.4	3.9	3.9
Reference [5]	435	950	0.458	3.8	3.4	3.9	3.9
average	412	950	0.434	3.6	3.4	3.9	3.9
^a Equation (2) with $K_s = 0.3$.							

6.3 Saturation Factors for Loading Crude Oil

The crude oil loading emission factors of [Table 2](#) were developed from [Table A.2](#), which is based on data for which P_{va} was 4 psia (see [A.3.2](#)) and M_v was 58 lb/lb-mole and the vapor temperature T_v was 530 °R (see [Table A.3](#)). Substituting these values into Equation (2):

$$L_L \text{ lb/(1000 gal loaded)} = 12.46 K_s(4 \text{ psia})(58 \text{ lb/lb-mole})/(530 \text{ °R})$$

$$L_L \text{ lb/(1000 gal loaded)} = 5.5 K_s$$

[Table A.2](#) provides the crude oil loading loss L_L for various vessels, prior cargos, and compartment treatments during the ballast voyage. These were used to determine the saturation factor K_s given in [Table 9](#) for these various conditions. For example ², for a ship or ocean barge whose prior cargo was volatile and compartment was uncleaned prior to loading, the saturation factor K_s for crude oil loading is:

$$1.1 = 5.5 K_s, \text{ so } K_s = 1.1/5.5 = 0.2$$

The emission factors from [Table A.2](#) and the corresponding saturation factors, where $K_s = L_L/5.5$, are summarized as follows. [Table 2](#) saturation factors were rounded to the nearest 0.05.

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