

Manual of Petroleum Measurement Standards Chapter 19.6.2

Evaporative Loss from the Cleaning of Storage Tanks

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Introduction

The purpose of this standard is to provide guidance for estimating emissions that result from forced ventilation of a storage tank, such as is commonly utilized while cleaning the bottoms of aboveground storage tanks. This forced ventilation is sometimes referred to as degassing.

While a given tank may be cleaned only once every 10 to 20 years, regulations may require reporting the resulting emissions when this does occur. Furthermore, petroleum industry facilities may be required to estimate emissions from all sources within their plant sites. These regulatory requirements include Toxic Release Inventory reporting under EPCRA Section 313 and annual emissions reporting under the Part 70 operating permit program. Given these requirements to report emissions, there is a need for guidance on how to estimate them.

Emission factors have been developed for most of the routine sources of emissions from petroleum-related facilities, but little guidance has been available for estimating emissions from non-routine sources. When non-routine events occur, companies often expend a significant effort in preparing a good-faith estimate of the resulting emissions. In the absence of any industry-wide practice or guidance, however, these estimates may vary widely.

This standard is intended to reduce the effort required to generate a good-faith estimate of tank cleaning emissions, and to result in more uniformity in the resulting emission estimates.

This standard replaces [API Technical Report 2568](#), *Evaporative Loss from the Cleaning of Storage Tanks*, 1st Edition, November 2007. [TR 2568](#) has been withdrawn.

Evaporative Loss from the Cleaning of Storage Tanks

1 Scope

This standard provides guidance for estimating emissions that result from forced ventilation of storage tanks such as may occur while removing the liquid heel (free-standing stock liquid) and cleaning the remaining deposits of stock liquid mixed with residue and water (sludge) from the bottoms of aboveground storage tanks.

The emissions addressed in this report are those that leave the tank during forced ventilation. This standard does not address:

- the fate of vapors after they have left the tank (other than accounting for the efficiency of a control device, as discussed in Section 8),
- the fate of sludge after it has left the tank (or emissions that may occur during sludge treatment or disposal), or
- emissions that may be expelled by the vacuum pump of a vacuum truck or suction pump, if such devices are used in the tank cleaning process.

In other words, this report addresses the estimation of the mass of volatile organic compounds that leave the tank as vapor during forced ventilation of the tank, such as may occur during a tank cleaning process such as is described in Annex E. It does not address emissions that may result from the handling of liquids or sludge after such materials have been removed from the tank.

This standard is not a guide for entering and cleaning storage tanks. Such procedures are addressed in [API 2015](#) ^[1] and [API 2016](#) ^[2].

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

[API Manual of Petroleum Measurement Standards \(MPMS\) Chapter 19.1](#), *Evaporative Loss from Fixed-roof Tanks*, Fifth Edition, June 2017

[API Manual of Petroleum Measurement Standards \(MPMS\) Chapter 19.4](#), *Evaporative Loss Reference Information and Speciation Methodology*, Third Edition, October 2012 (including Addendum 2, June 2017)

[API Manual of Petroleum Measurement Standards \(MPMS\) Chapter 19.6.1](#), *Evaporative Loss from Storage Tank Floating-roof Landings*, First Edition, February 2017

3 Variables and Symbols

C_V is the average vapor concentration by volume during continued forced ventilation (dimensionless), as determined from 6.2

D is the tank diameter (in feet), as specified by the user

d_s is the average sludge depth (in inches), as specified by the user

F_e is the fraction of the sludge that evaporates (dimensionless), as specified by the user
= 0.20 if unknown (from A.2)

H_{RO} is the roof outage (the effective height of the vapor space enclosed by the tank roof) (in feet), as specified by the user
= $s_r D / 72$ for a cone-roof tank

H_S is the height of the tank shell (in feet), as specified by the user

H_{VO} is the fixed-roof tank vapor space outage (in feet)
= $H_S - h_l + H_{RO}$

h_d is the height of the floating-roof deck above the tank bottom at the tank shell (in feet), as specified by the user; see Figure 1 (from [API MPMS Ch. 19.6.1](#))

h_l is the height of the stock liquid and sludge above the tank bottom at the tank shell for a given stage in the tank cleaning process (in feet), as specified by the user; see Figure 1

h_{le} is the effective height of the stock liquid and sludge for a given stage in the tank cleaning process (in feet), as determined from Table 1

h_p the vertical distance from the bottom of the shell down to the liquid surface of a partial heel in a cone-down bottom (in feet), as determined from Table 1

h_v is the height of the vapor space under a floating roof for a given stage in the tank cleaning process (in feet), from Table 1; see Figure 1

I is the daily total insolation on a horizontal surface [in Btu/(ft² day)], as specified by the user or [API MPMS Ch. 19.4](#)

K_E is the vapor space expansion factor (dimensionless)

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{\Delta P_V}{P_A - P_{VA}} \geq 0$$

see [API MPMS Ch. 19.1](#) for alternative equations for K_E

K_S is the standing idle saturation factor (dimensionless), as calculated per Section 4

L_C is the total tank cleaning emissions (in pounds)
= $L_S + L_P + L_{CV} + L_F$

L_{CV}	is the continued forced ventilation loss per cleaning (in pounds), as calculated per Section 6
L_F	is the filling loss per cleaning (in pounds), as calculated per Section 7
L_P	is the vapor space purge loss per cleaning (in pounds), as calculated per Section 5
L_S	is the standing idle loss per cleaning (in pounds), as calculated per Section 4
M_{CG}	is the molecular weight of the lower explosive limit (LEL) monitor calibration gas (in pounds per pound-mole), as specified by the user
M_V	is the stock vapor molecular weight (in pounds per pound-mole), as specified by the user or API MPMS Ch. 19.4
n_{CV}	is the time for continued forced ventilation (in days), as specified by the user
n_c	is the number of air changes per unit time during continued forced ventilation (in hours ⁻¹), as specified by the user
n_d	is the time the tank stands idle (in days), as specified by the user
P_a	is the atmospheric pressure at the tank location (in pounds per square inch absolute), as specified by the user
P_{VA}	is the true vapor pressure of the exposed volatile material in the tank at the average daily liquid surface temperature (in pounds per square inch absolute), as specified by the user or API MPMS Ch. 19.4
P_{VN}	is the true vapor pressure of the exposed volatile material in the tank at the minimum daily liquid surface temperature, T_{LN} (in pounds per square inch absolute), as specified by the user or API MPMS Ch. 19.4
P_{VX}	is the true vapor pressure of the exposed volatile material in the tank at the maximum daily liquid surface temperature, T_{LX} (in pounds per square inch absolute), as specified by the user or API MPMS Ch. 19.4
P^*	is a vapor pressure function (dimensionless)
	$= \frac{P_{VA} / P_a}{\left(1 + \left[1 - (P_{VA} / P_a)\right]^{0.5}\right)^2}$
Q_v	is the ventilation rate during continued forced ventilation (in cubic feet/minute), as specified by the user
R	is the ideal gas constant [in psia-ft ³ /(lb-mole °R)]
	$= 10.731$
RF	is the response factor for a given LEL monitor to a given vapor composition (dimensionless) as specified by the user
	$= 1.0$ if unknown
S	is the saturation factor (dimensionless), as stipulated in Table 2 and Table 3
s	is the slope of the tank bottom [in inches (per foot)] as specified by the user

s_r	is the slope of a cone-shaped roof [in inches (per foot)] as specified by the user
T_{LA}	is the average temperature of the liquid surface (in degrees Rankine), as specified by the user or $= \text{avg ambient temp } (^{\circ}\text{F}) + 459.7$
T_{LN}	is the average daily minimum temperature of the liquid surface (in degrees Rankine) $= T_{LA} - 0.25\Delta T_V$
T_{LX}	is the average daily maximum temperature of the liquid surface (in degrees Rankine) $= T_{LA} + 0.25\Delta T_V$
T_{MAX}	is the average daily maximum ambient temperature (in degrees Fahrenheit), as specified by the user
T_{MIN}	is the average daily minimum ambient temperature (in degrees Fahrenheit), as specified by the user
T_V	is the average temperature of the vapor space (in degrees Rankine), as specified by the user or $= \text{avg ambient temp } (^{\circ}\text{F}) + 459.7$
t_v	is the daily period of forced ventilation [in hours (per day)] as specified by the user
V_V	is the volume of the vapor space (in cubic feet) $= (h_v)\pi D^2/4 \text{ (floating-roof tanks)}$ $= (H_{VO})\pi D^2/4 \text{ (fixed-roof tanks)}$
W_l	is the stock liquid density (in pounds per gallon), as specified by the user or API MPMS Ch. 19.4
α	is the tank surface solar absorptance (dimensionless), as specified by the user or API MPMS Ch. 19.4
ΔP_V	is the daily stock vapor pressure range (in pounds per square inch absolute), $= P_{VX} - P_{VN}$
ΔT_V	is the daily vapor temperature range (in degrees Rankine), $= 0.7(T_{MAX} - T_{MIN}) + 0.02\alpha I, \text{ or}$ $= 20^{\circ}\text{F } (= 20^{\circ}\text{R}) \text{ if unknown}$

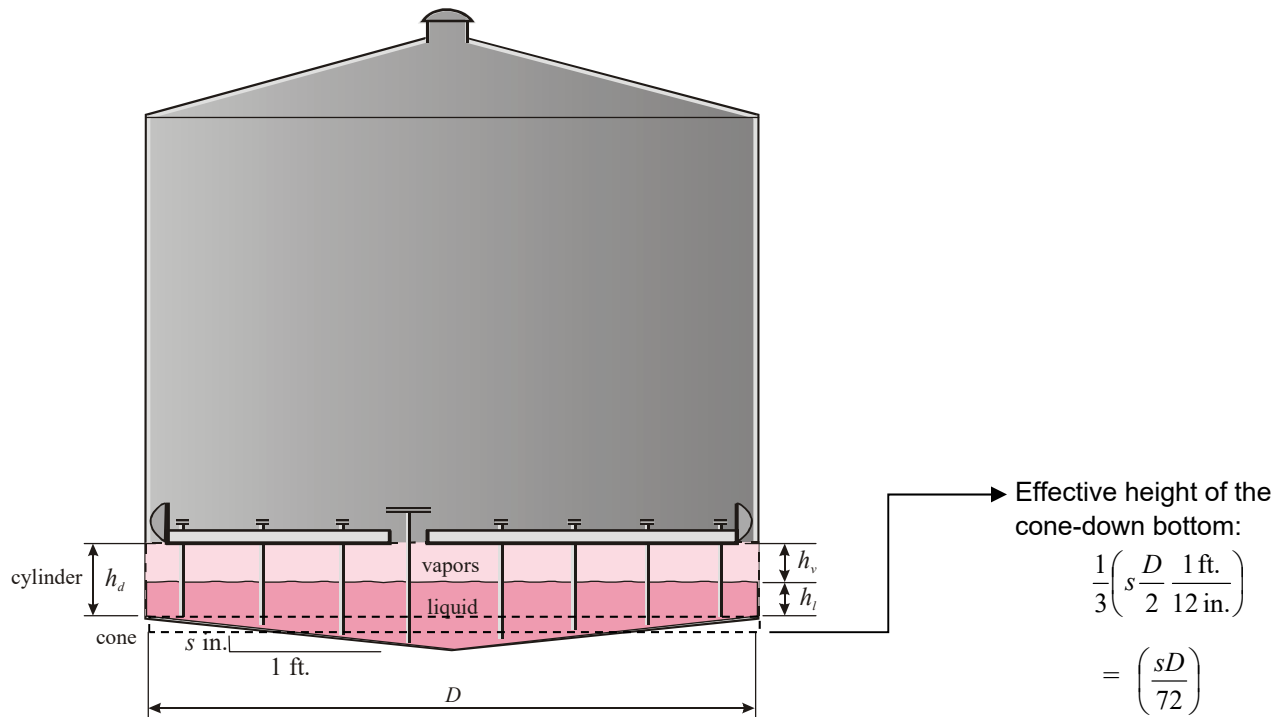


Figure 1—Height of the Vapor Space Under a Landed Floating Roof

Table 1—Height of the Vapor Space Under a Floating Roof

Scenario	Condition	Expression for Height of the Vapor Space (h_v)
General expression	Slope convention: s is expressed in inches (per foot); positive for cone down, negative for cone up	$h_v = \left(h_d + \frac{sD}{72} \right) - h_{le}$
Full liquid heel	$h_{le} = \left(h_l + \frac{sD}{72} \right)$	$h_v = h_d - h_l$
Partial liquid heel (this condition may occur after normal pumpout of a tank with a cone-down bottom, or be created during the tank cleaning process of any tank that had a full liquid heel after normal pumpout)	h_p is the vertical distance from the bottom of the shell down to the liquid surface in a cone-down bottom h_{le} is the height that would result from spreading the available volatile materials evenly over a flat tank bottom $h_{le} = \left(\frac{\text{volume of heel, ft}^3}{\pi D^2 / 4} \right) + \text{clingage}$	volume of heel, $\text{ft}^3 =$ $\left(\frac{\pi D^2}{12} \right) \frac{\left(\frac{sD}{24} - h_p \right)^3}{\left(\frac{sD}{24} \right)^2}$ $h_v = \left(h_d + \frac{sD}{72} \right) - \left[\left(\frac{\text{volume of heel, ft}^3}{\pi D^2 / 4} \right) + \left(\frac{0.01 \text{ in.}}{12 \text{ in./ft}} \right) \right]$
No significant amount of volatile material remaining (drain dry tanks or any tank after sludge removal)	$h_{le} = 0$	$h_v = \left(h_d + \frac{sD}{72} \right)$
Flat bottom (including slight cone-up bottoms)	$s = 0$ h_{le} is evaluated per the applicable case above	$h_v = h_d - h_{le} \{ = h_d - h_l, \text{ given } s = 0 \}$

Table 2—Summary of Tank Cleaning Emissions

Standing Idle Emissions			
Fixed-roof Tanks	Internal Floating-roof Tanks (IFRTs) with a Liquid Heel	External Floating-roof Tanks (EFRTs) with a Liquid Heel	Drain Dry Floating-roof Tanks
Initial standing idle period upon emptying the tank (Section 4):			
Included with normal standing storage (breathing) losses (see API MPMS Ch. 19.1) Thus, $L_S = 0$	[Equations (1) and (2)] $L_S = n_d K_E \left(\frac{P_{VA} V_V}{RT_V} \right) M_V K_S$ $\leq 5.9 D^2 h_{le} W_l$	[Equations (6) and (2)] $L_S = 0.57 n_d D P^* M_V$ $\leq 5.9 D^2 h_{le} W_l$	[Equations (8) and (9)] $L_S = 0.0063 W_l (\pi/4) D^2$ $\leq P_{VA} V_V M_V S / (RT_V)$ where $S = 0.6$
Subsequent (overnight) standing idle periods during the daily cleaning cycle (Section 6):			
$L_S = 0$	$L_S = 0$	$L_S = 0$	$L_S = 0$
Vapor Space Purge Emissions			
[Equation (10)] $L_P = \left(\frac{P_{VA} V_V}{RT_V} \right) M_V S$, where V_V and S are evaluated as shown below:			
Fixed-roof Tanks	Floating-roof Tanks		
[Equation (11)] $V_V = H_{VO}(\pi D^2/4)$	[Equation (4)] $V_V = (h_v)(\pi D^2/4)$		
	Full Liquid Heel	Partial Liquid Heel	Drain Dry Tanks
Initial vapor space purge upon commencing forced ventilation (Section 5):			
[Equations (13)–(15)] $S = \frac{0.5 n_d + 1}{6}$ ≥ 0.25 ≤ 0.5	[Equation (17); Table 4] IFRT $S = 0.6$ EFRT S is taken as $C_{sf} S =$ $0.6 \left(1 - \frac{\frac{0.57 D P^* R T_V}{P_{VA} V_V} - K_E K_S}{K_E K_S + 0.6} \right)$	[Equation (17); Table 4] IFRT $S = 0.5$ EFRT S is taken as $C_{sf} S =$ $0.5 \left(1 - \frac{\frac{0.57 D P^* R T_V}{P_{VA} V_V} - K_E K_S}{K_E K_S + 0.5} \right)$	(Table 4) $S = 0$
Subsequent vapor space purge emissions during the daily cleaning cycle, after standing idle overnight (Section 6):			
$S = 0.25$	$S = 0.6$	$S = 0.5$	$S = 0$
Continued Forced Ventilation Emissions (Section 6)			
<i>Applicable to all tank types (continued forced ventilation of the vapor space after a vapor space purge)</i>			
Vapor concentration method	[Equations (19) and (21)] $L_{CV} = 60 Q_v n_{CV} t_v C_V \frac{P_a M_{CG}}{RT_V}$ where $C_V \leq P_{VA}/P_a$	[Equation (2)] When a liquid heel is present: $L_{CV} \leq 5.9 D^2 h_{le} W_l$	[Equation (22)] If drain dry, or after the liquid heel has been vacuumed out: $L_{CV} \leq 0.49 F_e D^2 d_s W_l$
Refilling Emissions (Section 7)			
[Equation (23)] $L_F = \left(\frac{P_{VA} V_V}{RT_V} \right) M_V S$, where $S = 0.15$ and V_V is evaluated as shown below:			
Fixed-roof Tanks	Floating-roof Tanks		
Included with normal working losses (see API MPMS Ch. 19.1) Thus, $L_F = 0$	[Equation (4)] $V_V = (h_v)(\pi D^2/4)$		

4 Standing Idle Emissions

4.1 General

The *standing idle* stage applies to any period during which volatile materials remain in an emptied tank while forced ventilation is not taking place. The first standing idle period for a tank cleaning episode occurs after normal pumpout to empty the tank is complete. During this time, any volatile material that remains in the tank may evaporate, thereby generating vapors into the vapor space of the tank. Each day that the tank stands idle, a portion of these vapors will be expelled from the tank by the expansion of the air/hydrocarbon mixture (i.e. vapors) that results from daytime heating of the vapor space. Nighttime cooling draws fresh air into the tank, which in turn promotes additional evaporation. This daily cycle of generating vapors and expelling a portion of them, in response to ambient temperature swings, is referred to as *breathing*. Emissions from this standing idle period are estimated as discussed in 4.2 and 4.3.

When the standing idle period is limited to an overnight cessation of forced ventilation, however, the standing idle emissions for that overnight period are accounted for in the estimate of the next morning's vapor space purge, as described in Section 6.

4.2 Fixed-roof Tanks

The *standing idle* emissions for fixed-roof tanks are estimated as normal standing storage (breathing) losses, as specified in [API MPMS Ch. 19.1](#). This initial standing idle time should be included in the number of days that the tank is considered to be in service for estimating normal standing storage losses for a fixed-roof tank, and thus this initial standing idle period should not be included with the estimate of tank cleaning emissions. Thus:

$$L_S = 0, \text{ for fixed-roof tanks}$$

4.3 Floating-roof Tanks

4.3.1 General

A method for estimating emissions while a floating-roof tank is standing idle (with the floating roof landed on its support legs) is presented in [API MPMS Ch. 19.6.1](#). This method is outlined below.

4.3.2 Internal Floating-roof Tanks with a Full or Partial Liquid Heel

For internal floating-roof tanks (IFRTs) with a full or partial liquid heel, the standing idle loss is:

$$L_S = n_d K_E \left(\frac{P_{VA} V_V}{R T_V} \right) M_V K_S \quad (1)$$

limited by:

$$L_S \leq (\pi/4)(D \text{ ft})^2 (h_{le} \text{ ft})(W_l \text{ lb/gal})(7.48 \text{ gal/ft}^3)$$

$$L_S \leq 5.9 D^2 h_{le} W_l \quad (2)$$

where

n_d is the time that the tank stands idle (days);

K_E is the vapor space expansion factor (dimensionless),

$$= \frac{\Delta T_V}{T_{LA}} + \frac{\Delta P_V}{P_A - P_{VA}} \quad (3)$$

(see [API MPMS Ch. 19.1](#) for alternative equations for K_E);

P_{VA} is the true vapor pressure of the exposed volatile material in the tank (psia);

V_V is the volume (ft³) of the vapor space under the floating roof,

$$= (h_v)(\pi D^2/4) \quad (4)$$

h_v is the height (ft) of the vapor space under the floating roof for the given standing idle period (see Table 1);

D is the tank diameter (ft);

R is the ideal gas constant [psia-ft³/(lb-mole °R)],

$$= 10.731 \text{ [psia-ft}^3\text{/(lb-mole °R)]};$$

T_{LA} is the average temperature of the liquid surface (°R),

is the average ambient temperature (°R);

NOTE Given the proximity of the liquid heel to the bottom of the tank, the temperature of the ground beneath the tank is assumed to dominate the temperature of the liquid heel. The ground temperature is assumed to be equal to the average ambient temperature, and thus the liquid bulk and liquid surface temperatures may be reasonably represented by the average ambient air temperature unless the user has information on the actual temperature of the bulk liquid in the heel.

M_V is the stock vapor molecular weight (lb/lb-mole);

K_S is the standing idle saturation factor (dimensionless),

$$= \frac{1}{1 + 0.053 P_{VA} (h_v)} \leq S \quad (5)$$

(where S equals 0.6 for a full heel and 0.5 for a partial heel);

h_{le} is the effective height (ft) of the stock liquid and sludge for the given standing idle period (see Table 1);

W_l is the stock liquid density (lb/gal).

4.3.3 External Floating-roof Tanks with a Full or Partial Liquid Heel

For external floating-roof tanks (EFRTs) with a full or partial liquid heel, the standing idle loss is:

$$L_S = 0.57 n_d D P^* M_V \quad (6)$$

limited by:

$$L_S \leq 5.9 D^2 h_{le} W_l \quad (2)$$

where

$$P^* = \frac{P_{VA} / P_a}{\left(1 + \left[1 - (P_{VA} / P_a)\right]^{0.5}\right)^2} \quad (7)$$

P_a is the atmospheric pressure at the tank location (psia).

The other variables are evaluated as above.

4.3.4 Drain Dry Floating-roof Tanks

As discussed in [API MPMS Ch. 19.6.1](#), the term *drain dry* refers to a tank that is designed to drain its entire bottom to a sump in a manner that leaves no free-standing liquid in the tank or the sump. The only stock liquid available for evaporation in a drain dry tank is that which clings to the tank bottom and other wetted surfaces under the floating roof. In the event that a tank retains a pool of liquid in the bottom of a sump or in puddles, it should not be characterized as *drain dry*, but rather should be considered to have a *partial liquid heel*.

During the tank cleaning process, the tank may be considered to be in a drain dry condition after all free-standing stock liquid has been removed from the tank.

For all drain dry floating-roof tanks, the standing idle loss is:

$$L_S = 0.0063 W_I (\pi/4) D^2 \quad (8)$$

where the coefficient 0.0063 has units of gal/ft², as derived in [API MPMS Ch. 19.6.1](#), which corresponds to a clingage thickness of 0.010 in.

limited by:

$$L_S \leq P_{VA} V_V M_V S / (RT_V) \quad (9)$$

The volume of the vapor space (V_V) is equal to $(h_v)(\pi D^2/4)$, and $S = 0.60$. All other variables are evaluated as described above.

5 Vapor Space Purge Emissions

5.1 General

The daily breathing cycle that produces the *standing idle* emissions causes only a portion of the vapors in the vapor space to be expelled from the tank. The vapors that remain in the vapor space are not accounted for in the calculation of standing idle emissions. Commencement of forced ventilation expels these remaining vapors from the tank. *Forced ventilation*, as used in this report, refers to any expulsion of vapors from a tank by means of eductors, fans, blowers, or other air moving devices, regardless of whether or not the vapors are collected or treated upon being expelled from the tank. The first air change of the vapor space upon commencing forced ventilation may be referred to as the *vapor space purge*, and the emissions may be estimated as follows:

$$L_P = \left(\frac{P_{VA} V_V}{RT_V} \right) M_V S \quad (10)$$

where

P_{VA} is the true vapor pressure of the exposed volatile material in the tank (psia);

V_V is the volume (ft³) of the vapor space;

R is the ideal gas constant [psia-ft³/(lb-mole °R)],
= 10.731 psia-ft³/(lb-mole °R);

T_V is the average temperature of the vapor space (°R),

is the average ambient temperature (°R) unless specified otherwise by the user;

M_V is the stock vapor molecular weight (lb/lb-mole);

S is a saturation factor, evaluated as shown in Table 3 (see 5.2 and 5.3 for the determination of these saturation factor values).

Table 3—Summary of Saturation Factors (*S*) for Vapor Space Purge

Fixed-roof Tanks	Floating-roof Tanks		
	Full Liquid Heel	Partial Liquid Heel	Drain Dry Tanks
Initial vapor space purge upon commencing forced ventilation (Section 5):			
[Equations (13)–(15)] $S = \frac{0.5n_d + 1}{6}$ ≥ 0.25 ≤ 0.5	[Equation (17); Table 4] IFRT $S = 0.6$ EFRT S is taken as $C_{sf}S =$ $0.6 \left(1 - \frac{\frac{0.57DP^*RT_V}{P_{VA}V_V} - K_EK_S}{K_EK_S + 0.6} \right)$	[Equation (17); Table 4] IFRT $S = 0.5$ EFRT S is taken as $C_{sf}S =$ $0.5 \left(1 - \frac{\frac{0.57DP^*RT_V}{P_{VA}V_V} - K_EK_S}{K_EK_S + 0.5} \right)$	(Table 4) $S = 0$
Subsequent vapor space purge emissions during the daily cleaning cycle, after standing idle overnight (Section 6):			
$S = 0.25$	$S = 0.6$	$S = 0.5$	$S = 0$

The vapor space purge comprises the expulsion of one vapor space volume, similar to one working-loss (filling) cycle of the vapor space. Emissions from the initial vapor space purge (following the initial period of standing idle after normal pumpout) are estimated as discussed in 5.2 and 5.3. Emissions associated with subsequent air changes are accounted for as continued forced ventilation emissions, as discussed in Section 6.

When the vapor space purge follows a standing idle period that was limited to an overnight cessation of operations, then the emissions from the next morning's vapor space purge (first air change) are estimated as described in Figure 2. As with the initial vapor space purge, emissions from subsequent air changes following these daily vapor space purges are accounted for as continued forced ventilation emissions.

The volatility of the remaining materials may be less than the volatility of the previously stored stock liquid, and thus an appropriate judgment should be made in assigning properties to the residual material in the tank bottom for purposes of determining values for the true vapor pressure, P_{VA} , and the stock vapor molecular weight, M_V .

For example, the bottom of the tank may be flooded with a light distillate material, such as diesel, to facilitate removal of sludge from the bottom of the tank. This procedure is referred to as distillate flushing. Testing has shown that when the characteristics of the liquid heel beneath a landed floating roof are changed, the characteristics of the vapor space beneath the floating roof will tend toward equilibrium with the new liquid heel within 24 hr. See Annex D for a more detailed discussion of distillate flushing.

The values for P_{VA} and M_V may then be based on the properties of the mixture resulting from distillate flushing the day following the introduction of the distillate into the tank. Properties of this mixture would be a weighted average of the properties of the original heel and the properties of the distillate material, proportional to the remaining quantities of each.

5.2 Fixed-roof Tanks

The volume of the vapor space for estimating working loss from a fixed-roof tank is calculated from the maximum liquid height to which the tank may be filled. For a vapor space purge, however, the volume of the vapor space is the entire volume under the tank roof:

$$V_V = H_{VO}(\pi D^2/4) \quad (11)$$

where

$$\begin{aligned} H_{VO} & \text{ is the fixed-roof tank vapor space outage (ft) ,} \\ & = H_S - h_l + H_{RO} \end{aligned} \quad (12)$$

where

$$\begin{aligned} H_S & \text{ is the height of the tank shell (ft);} \\ h_l & \text{ is the height of the stock liquid and sludge above the tank bottom at the tank shell (ft);} \\ H_{RO} & \text{ the roof outage [the effective height of the vapor space enclosed by the tank roof (ft)],} \\ & = s_r D/72 \text{ for a cone-shaped roof} \end{aligned}$$

where

$$s_r \text{ is the roof slope in inches per foot.}$$

The vapor space outage, H_{VO} , would be slightly greater for the case of a cone-down bottom in a tank that does not have a full liquid heel. The slope of bottoms tends to be much less than the slope of roofs, however, and the contribution of the bottom cone to the vapor space outage would be very small compared to the full shell height.

The saturation factor for filling a fixed-roof tank is given as the turnover factor (K_N) in [API MPMS Ch. 19.1](#) .

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

where

$$N \text{ is the turnover rate (year}^{-1}\text{).}$$

It would be advantageous to express this saturation factor in terms of days between turnovers (i.e. days standing idle, n_d). The number of days between turnovers may be expressed as follows:

$$n_d = 365/N$$

and thus:

$$1/n_d = N/365$$

Multiplying the right side of the equation for K_N by the equality $(1/365)/(1/365)$:

$$K_N = \frac{(180/365) + (N/365)}{6N/365}$$

and thus:

$$K_N = \frac{(180/365) + (1/n_d)}{6/n_d}$$

which simplifies to:

$$K_N = \frac{0.5 n_d + 1}{6}$$

Recognizing that the turnover factor (K_N) is the saturation factor to be used for calculating filling losses from a fixed-roof tank, the saturation factor (S) may be substituted for the turnover factor (K_N).

$$S = \frac{0.5 n_d + 1}{6} \quad (13)$$

For periods of less than 1 day, such as an overnight cessation of forced ventilation, a value of 1 should be used for the standing idle time (n_d). This effectively imposes a minimum value of 0.25 for the saturation factor (S).

The saturation factor (S) for an IFRT with a partial heel may be reasonably chosen as an upper bound. This is equal to 0.5, as shown in Table 4. While this will give a lower result for the saturation factor (S) than the assumed value of 1 that may be inferred from the turnover factor (K_N) for fewer than 36 turnovers per year in [API MPMS Ch. 19.1](#), it is shown to be conservative by the S values used for estimating IFRT landing losses. The IFRT landing loss values were spot-validated by field testing and were based on a vapor space height limited to the space under the landed floating roof.

The height of the vapor space (H_{VO}) in a fixed-roof tank is the full height of the tank. It would be expected, for a given diameter of tank and type of liquid heel, that the accumulated vapors would be less concentrated in the larger vapor space of the fixed-roof tank than under a landed floating roof, and thus a value of 0.5 should be a conservative upper bound for the fixed-roof tank vapor space purge saturation factor.

These limits are expressed as follows:

$$S \geq 0.25 \quad (14)$$

$$S \leq 0.5 \quad (15)$$

5.3 Floating-roof Tanks

The volume of the vapor space for estimating the vapor space purge loss from a floating-roof tank is limited to the space under the floating roof, in that vapors that escape past the floating roof prior to the commencement of forced ventilation are separately accounted for as standing idle loss from the floating-roof landing event.

$$\begin{aligned} V_V & \text{ is the volume (ft}^3\text{) of the vapor space under the floating roof,} \\ & = (h_v)(\pi D^2/4) \end{aligned} \quad (4)$$

where

$$h_v \text{ is the height (ft) of the vapor space under the floating roof for the given vapor space purge (see Table 1).}$$

The saturation factor (S) for the initial vapor space purge is evaluated as specified for the filling saturation factor in [API MPMS Ch. 19.6.1](#). This approach is conservative in that filling losses have both an arrival component, from resident vapors, and a generated component from vapors generated by incoming liquid (e.g. 25 % of the filling saturation factor for an IFRT with a full liquid heel may be attributable to the incoming liquid).

contribution of the incoming liquid to the vapor concentration varies with the filling scenario). The vapor space purge does not involve incoming liquid, however, and therefore would have only the arrival component of vapors. It is conservative, therefore, to use saturation factors that include allowance for the generated component of vapors.

Values to be used are summarized in Table 4. The factors for EFRTs given in Table 4 are determined from the $C_{sf}S$ term given in [API MPMS Ch. 19.6.1](#), Table 1:

$$C_{sf}S = \left(1 - \frac{0.57n_d DP^* M_V - n_d K_E (P_{VA} V_V / RT_V) M_V K_S}{n_d K_E (P_{VA} V_V / RT_V) M_V K_S + (P_{VA} V_V / RT_V) M_V S} \right) S \quad (16)$$

Where the number of days, n_d , is taken as 1 day. This reduces to:

$$C_{sf}S = \left(1 - \frac{0.57 DP^* (RT_V / P_{VA} V_V) - K_E K_S}{K_E K_S + S} \right) S \quad (17)$$

Table 4—Saturation Factors (S) for the Initial* Vapor Space Purge of Floating-roof Tanks

Tank Type	Value for S ($C_{sf}S$ for EFRTs) in Equation (10)
Full liquid heel	
IFRT	0.6
EFRT	$0.6 \left(1 - \frac{\frac{0.57 DP^* RT_V}{P_{VA} V_V} - K_E K_S}{K_E K_S + 0.6} \right)$
Partial liquid heel	
IFRT	0.5
EFRT	$0.5 \left(1 - \frac{\frac{0.57 DP^* RT_V}{P_{VA} V_V} - K_E K_S}{K_E K_S + 0.5} \right)$
Drain dry (IFRT or EFRT)	0.0 Clingage has been accounted for, and there is no incoming liquid to generate more vapors.
* The initial vapor space purge occurs at the end of the standing idle period that immediately follows normal pumpout. Saturation factors for subsequent vapor space purges (i.e. those that follow overnight periods of standing idle, for which emissions are not calculated) are discussed in Section 6.	

6 Continued Forced Ventilation Emissions

6.1 Overview of Methodology

The calculation of *vapor space purge* emissions account for the vapors that are expelled by the first air change of the vapor space upon commencing forced ventilation at the end of a standing idle period. There may still be volatile materials remaining in the tank, however, that will continue to evaporate and generate vapors. These additional vapors are expelled by continued forced ventilation.

Three methods were considered for estimating continued forced ventilation emissions, and each may be applied to either fixed-roof or floating-roof tanks. The rationale for selecting the *vapor concentration method* described in this section is given in Annex A, where the other methods are discussed and compared to the vapor concentration method.

The vapor concentration method estimates continued forced ventilation emissions from the average vapor concentration in the vapor space (which may be reported as a percent of the lower explosive limit, or %LEL), the ventilation rate, and the length of time during which forced ventilation continues to operate. These parameters are often known since they may be monitored for safety reasons.

The vapor concentration may be approximated from the reading of an LEL monitor, which is generally displayed as a percent of the LEL for the gas to which the monitor has been calibrated. LEL values for selected calibration gases are given in Table 5. The vapor concentration may also be approximated from the reading of an organic or toxic vapor analyzer, which may display in parts per million by volume as the calibration gas.

Table 5—LEL Values for Selected Compounds

Stock	LEL ^[6] (volume percent in air)
Heptane (C7)	1.05
Hexane (C6)	1.1
Pentane (C5)	1.5
Butane (C4)	1.9
Propane (C3)	2.1
Ethane (C2)	3.0
Methane (C1)	5.0

To determine the vapor concentration from a %LEL reading, the LEL of the calibration gas is multiplied by the reading from the LEL monitor, after each has been divided by 100 to convert from a percent to a decimal fraction. This gives a volume concentration (mole fraction) in terms of the calibration gas. This concentration is corrected by a response factor (*RF*) to account for the difference in the sensitivity of the LEL monitor to the actual vapors as compared to its sensitivity to the calibration gas. When the response factor is unknown, use a value of one (*RF* = 1.0). See Annex B for a discussion of LEL monitors and response factors.

If the vapor concentration is very low, it may be below the minimum detection level of the LEL monitor. In such cases, it may be reasonable to use half the minimum detection level as the %LEL for determining the vapor concentration.

The mass of vapors that escape the tank during continued forced ventilation is the product of the average density of the hydrocarbon vapors, the average ventilation rate, and the length of time over which forced ventilation continues to operate. The vapor concentration and ventilation rate may vary during continued forced ventilation (e.g. fans may not be operated continuously at a constant rate), but using the average concentration and ventilation rate would provide a reasonable approximation.

When forced ventilation is intermittently interrupted, such as during the overnight period, then the tank cleaning process will involve a daily cycle that includes a period of standing idle (overnight) followed by a vapor space purge (when forced ventilation resumes the next morning). Emissions from overnight standing idle periods are accounted for in the estimate of the next morning's vapor space purge.

In that the overnight standing idle emissions are taken as zero, there is no accounting for wind-driven losses of vapor from under external floating roofs. These vapors must then be accounted for with the following morning's vapor space purge. That is, the neglect of wind driven emissions during the overnight period means that the vapors must be considered to still be present when estimating the next morning's vapor space purge, and thus there must be no factoring down of the saturation level for the case of EFRTs. In other words, C_{sf} should be taken as 1.0 when the vapor space purge follows a standing idle period that was limited to an overnight cessation of forced ventilation.

Dislodging of the sludge may be done in a variety of ways, including circulation with a diluent, spraying with a stream of water, or physically removing the sludge with shovels or squeegees. The scenario of circulated diluent would be characterized by the properties of the mixture of diluent with the prior stock. See Annex D for a more detailed discussion of distillate flushing of the tank bottom.

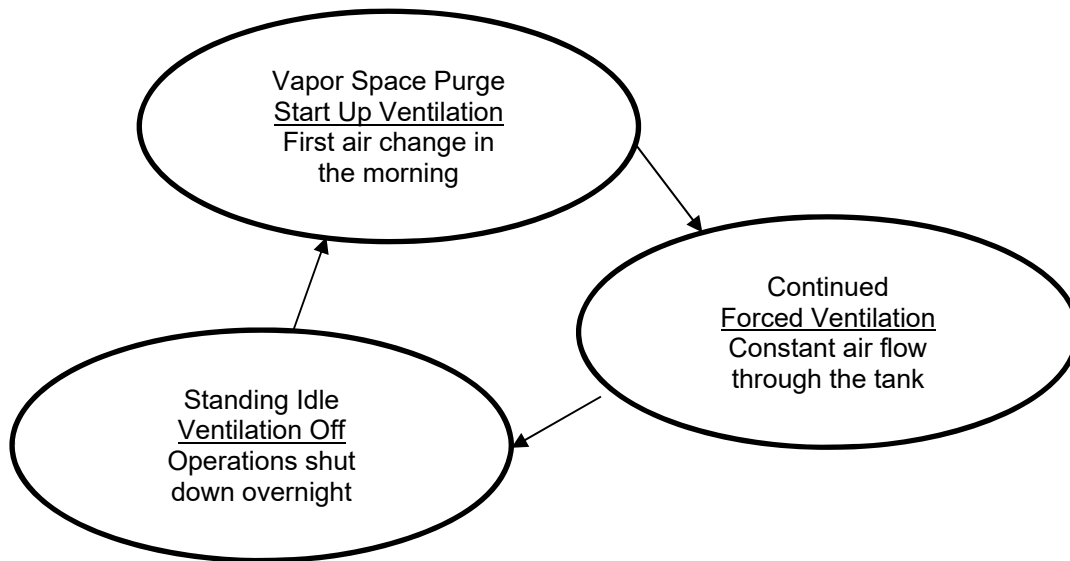
In the case of dislodging the sludge with a stream of water or a squeegee or shovel, there may not be a heel of volatile liquid. The volatile materials in the bottom of the tank are stirred up by these dislodging methods, however, and thus some off-gassing of these materials would be expected to take place overnight even in the case of drain dry tanks. In that the stirred-up sludge results in pockets of exposed volatile materials, this scenario may be represented as a partial heel condition. However, it may be reasonable to represent the properties of the sludge by a less volatile stock than that which had been previously stored in the tank.

The saturation factors for floating-roof tanks are likely to be conservative, as discussed in 5.3, in that there is no incoming liquid to contribute to vapor generation.

The assumed saturation factor of 0.25 for fixed-roof tanks is obtained from 5.2, for periods of less than 1 day. This is likely to be conservative in that the portion of day involved in the overnight period is only the relatively cool nighttime hours.

The scenarios to be considered in the estimation of emissions during the daily tank cleaning cycle are summarized in Figure 2.

Vapor Space Purge (per Day)			
[Equation (10)] $L_P = \left(\frac{P_{VA} V_V}{RT_V} \right) M_V S$, where V_V and S are evaluated as shown below:			
Fixed-roof Tanks	Floating-roof Tanks		
[Equation (11)] $V_V = H_{VO}(\pi D^2/4)$	[Equation (4)] $V_V = (h_v)(\pi D^2/4)$		
	Full Liquid Heel	Partial Liquid Heel	No Free-standing Liquid
$S = 0.25$	$S = 0.6$	$S = 0.5$	$S = 0$



Standing Idle	
All tanks	$L_S = 0$
(Overnight standing idle evaporation is accounted for with the next morning's vapor space purge)	

Continued Forced Ventilation	[Equations (19), (21), (2), and (22)]
All tanks	$L_{CV} = 60 Q_v n_{CV} t_v C_V \frac{P_a M_{CG}}{RT_V}$
Limit on concentration	$C_V \leq P_{VA}/P_a$
When a liquid heel is present	$L_{CV} \leq 5.9 D^2 h_{le} W_l$
After all free-standing liquid has been removed	$L_{CV} \leq 0.49 F_e D^2 d_s W_l$

Figure 2—Equations of the Daily Tank Cleaning Cycle

6.2 Derivation of the Vapor Concentration Method Equations

In order to estimate the mass of vapors that are expelled from the tank by continued forced ventilation, the vapor concentration in terms of volume must be converted to vapor density in terms of mass. Derivation of the necessary equations is shown below.

The vapor concentration (C_V), determined from the %LEL or read directly by a vapor analyzer, is a concentration by volume. This is also referred to as a mole fraction, in that the volume concentration is defined as the number of moles of the given substance divided by the total number of moles of the system (in this case, the system consists of the stock vapors plus air). That is:

$$C_V = \frac{(\text{no. moles stock vapor})}{(\text{total no. moles})}$$

And thus:

$$(\text{no. moles stock vapor}) = C_V (\text{total no. moles})$$

From the ideal gas law:

$$(\text{no. moles}) = \frac{PV}{RT}$$

Therefore:

$$(\text{total no. moles}) = \frac{P_T V}{RT}$$

where

$$\begin{aligned} P_T &\text{ is the total system pressure (which, for an opened tank, is approximately atmospheric pressure),} \\ &= P_a. \end{aligned}$$

And thus:

$$(\text{total no. moles}) = \frac{P_a V}{RT}$$

The number of moles of stock vapor may then be expressed as:

$$(\text{no. moles stock vapor}) = C_V \frac{P_a V}{RT}$$

Weight (mass) is the number of moles times the molecular weight. When concentration is measured by a vapor analyzer that has been calibrated to a given compound, the measured concentration is expressed in terms of that calibration compound. For example, if the instrument is calibrated with methane, then the measured concentration is expressed "as methane." The molecular weight of the calibration gas should therefore be used to convert the measured concentration to a density.

$$(\text{weight of stock vapor}) = \left[C_V \frac{P_a V}{RT} \right] M_{CG}$$

Recognizing that density is weight divided by volume:

$$(\text{density of stock vapor}) = C_V \frac{P_a M_{CG}}{RT}$$

The expression for weight may then be rearranged in terms of volume times density:

$$(\text{weight of stock vapor}) = V \left[C_V \frac{P_a M_{CG}}{RT} \right]$$

The total volume (V) expelled from the tank is:

$$V = (60 \text{ min/hr})(Q_v \text{ ft}^3/\text{min})(n_{CV} \text{ days})(t_v \text{ hr/day})$$

Therefore, the continued forced ventilation emissions (L_{CV}) estimated by the vapor concentration method are:

$$L_{CV} = (60 \text{ min/hr})(Q_v \text{ ft}^3/\text{min})(n_{CV} \text{ day})(t_v \text{ hr/day}) C_V \frac{(P_a \text{ psia})(M_{CG} \text{ lb/lb} \cdot \text{mole})}{(R \text{ psia ft}^3/\text{lb} \cdot \text{mole}^\circ\text{R})(T^\circ\text{R})} \quad (18)$$

Applying this expression to the vapor space inside a storage tank, the temperature to be used is the temperature of the vapor space.

$$L_{CV} = 60 Q_v n_{CV} t_v C_V \frac{P_a M_{CG}}{RT_V} \quad (19)$$

where

Q_v is the average ventilation rate (ft^3/min) during continued forced ventilation;

NOTE The nominal rated capacity of eductors, fans, or blowers should be factored by the resistance associated with ductwork or other obstructions in order to estimate the actual air flow rate. Fan capacity may be governed by a required number of air changes per hour. [API 2016](#) ^[2] specifies a minimum of 5 air changes per hour.

n_{CV} is the duration of continued forced ventilation (days);

t_v is the daily period of forced ventilation (hr/day);

NOTE Do not include the initial time for the vapor space purge. It would be reasonable to neglect the first half hour from each stage of continued forced ventilation.

C_V is the average vapor concentration by volume during continued forced ventilation, dimensionless,

$$= \frac{(\text{average \% LEL as displayed})}{100} \cdot \frac{(\text{LEL of the calibration gas, volume \% in air})}{100} \cdot RF \quad (20)$$

where

average % LEL as displayed is the average of the % LEL readings during a given stage of continued forced ventilation, divided by 100 to convert to a decimal fraction; LEL readings from the first half hour may be neglected in the determination of an average value;

LEL of the calibration gas is the LEL of the gas used to calibrate the LEL monitor, expressed as a decimal fraction (see Table 5);

alternatively, C_V may be obtained from an organic vapor analyzer or toxic vapor analyzer that displays directly in terms of volume concentration, rather than displaying in terms of % LEL;

RF is the response factor (dimensionless),

= 1.0 if unknown;

NOTE See Annex B for a discussion of LEL measurements and response factors.

P_a is the atmospheric pressure at the tank location (psia);

M_{CG} is the molecular weight of the LEL monitor calibration gas (lb/lb-mole);

R is the ideal gas constant,

= 10.731 psia-ft³/(lb-mole °R);

T_V is the average temperature of the vapor space (°R),

is the average ambient temperature (°R) unless specified otherwise by the user;

the constant, 60, has units of min/hr.

The vapor concentration (C_V) is limited by saturation of the vapor space. This limit may be expressed as:

$$C_V \leq P_{VA}/P_a \quad (21)$$

where

P_{VA} is the true vapor pressure of the exposed volatile material in the tank (psia).

The estimate of continued forced ventilation emissions should be compared to an upper limit equal to the total weight of volatile sludge remaining in the tank. While there is free-standing stock liquid remaining in the tank, the sludge may conservatively be assumed to consist entirely of stock liquid in establishing the emissions upper limit. This limit is expressed as follows:

$$L_S \leq 5.9D^2h_{le}W_l \quad (2)$$

where

D is the tank diameter (ft);

h_{le} is the effective height (ft) of the stock liquid and sludge for the given stage of continued forced ventilation (see Table 1);

W_l is the density of the stock liquid (lb/gal);

the constant, 5.9, has units of gal/ft³ (the product of the constant term $\pi/4$ and the conversion factor 7.48 gal/ft³).