Evaporative Loss from the Cleaning of Storage Tanks

TECHNICAL REPORT 2568
NOVEMBER 2007

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Measurement Coordination

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0. EXECUTIVE SUMMARY

0.1 Statement of Purpose

The purpose of this report is to provide guidance for estimating emissions that result from cleaning the bottoms of aboveground storage tanks. This report addresses vapors that leave the tank during the tank-cleaning process, but it 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.

The tank-cleaning process may be considered, for purposes of estimating emissions, as involving the following steps:

a) Normal Pumpout: As much stock liquid as possible is pumped out through the tank outlet in the normal manner (*i.e.*, until the liquid level has dropped below the open end of the outlet line, and no more liquid moves through the outlet). As the liquid level drops during *normal pumpout*, flow of air through the tank vents is from outside the tank to inside the tank. Given this inward direction of air flow, it is assumed that no emissions occur during normal pumpout.

b) Standing Idle: The defining characteristics of the *standing idle* condition are:
   - volatile material, capable of generating vapors, remains in the tank (as a full or partial liquid heel, or as clingage on the tank bottom),
   - the height of the vapor space is reasonably constant (change is limited to stripping of the heel, or pump in of diluent) during the period in question, and
   - there is no forced ventilation of the vapor space (*i.e.*, no eductors, fans, or blowers are engaged in expelling the air/hydrocarbon mixture (*i.e.*, vapors) from the tank).

   During a standing idle period, vapors are generated inside the tank by evaporation at the surface of the remaining volatile material. The diurnal temperature cycle causes expansion and contraction of the vapors in the tank, thereby causing some of these vapors to be expelled from the tank (in the same manner as for breathing losses from a fixed-roof tank).

c) Vapor Space Purge: As used in this report, *forced ventilation* refers to any expulsion of vapors from a tank by means of eductors, fans, or blowers, regardless of whether or not the vapors are collected or treated upon being expelled from the tank. When forced ventilation begins, outside air is drawn into the tank, displacing the vapors that remain from the prior period of standing idle. While it may require multiple air changes to actually remove all of these vapors, for purposes of estimating emissions these vapors are accounted for in the first air change. This first air change, then, represents the *vapor space purge*. Emissions associated with subsequent air changes are accounted for in the *sludge removal* step.

d) Sludge Removal: As used in this report, *sludge removal* refers to the removal of volatile materials from a tank while the tank is subject to forced ventilation. Volatile materials evaporate during sludge removal, thereby producing vapors that are expelled from the tank by the eductors, fans, or blowers. Sludge removal may take place as part of a daily cycle that includes periods of standing idle and vapor space purge. This cycle is illustrated in Figure 1.

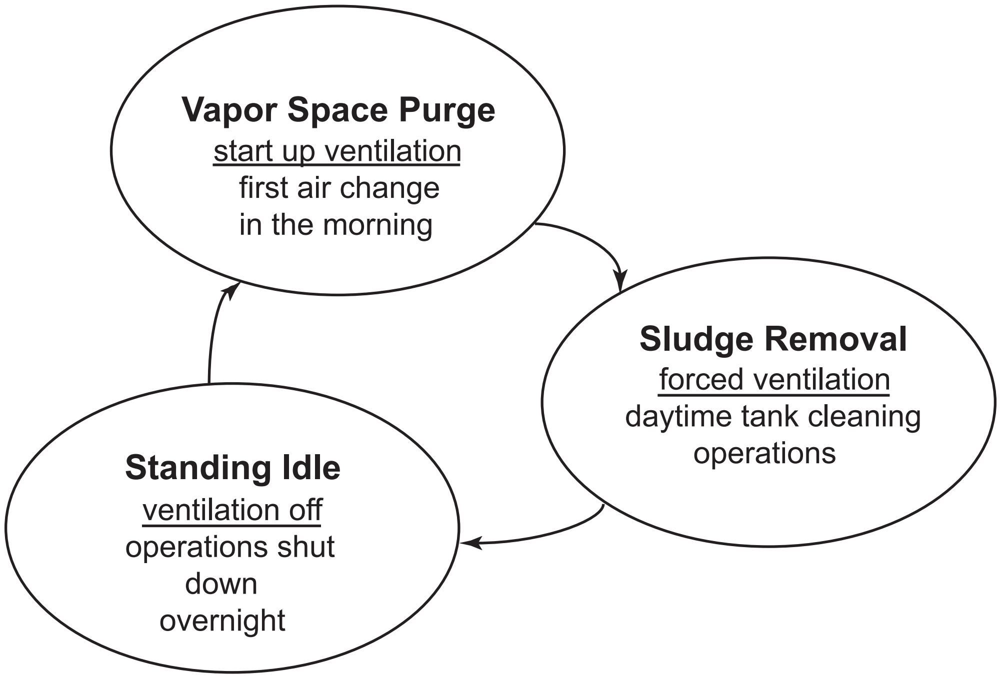


Figure 1—Daily Tank Cleaning Cycle

e) Remain Clean: Once the tank has been cleaned, it may remain in the clean condition for some period of time. In that there are no remaining sources of vapors once the tank has been cleaned, no further emissions will occur for as long as the tank remains clean.

f) Refilling: The clean tank is refilled. The incoming stock liquid generates vapors, which are then displaced from the tank as the stock liquid level rises.

The *normal pumpout* and *remain clean* steps do not involve emissions. Methods for estimating emissions from the *standing idle* and *refilling* steps are given in the API document *Evaporative Loss from Storage Tank Floating Roof Landings* [API Landing Loss Report].[1]

The purpose of this report is to provide guidance for applying the methods from the API Landing Loss Report[2] to the *standing idle* and *refilling* steps as they pertain to tank cleaning, as well as to provide guidance for estimating emissions from the other two steps: *vapor space purge* and *sludge removal*.

0.2 Estimating Method

The estimating method presented in this report is summarized in Table 1.

Table 1—Summary of Tank Cleaning Emissions

Standing Idle Emissions

Fixed Roof Tanks	Internal Floating Roof Tanks with a Liquid Heel	External Floating Roof Tanks 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 19.1[3]) Thus $L_S = 0$	{equations 9 & 10} $L_S = n_d K_E \left(\frac{PV_V}{RT}\right) M_V K_S$ $\leq 5.9D^2 h_{le} W_l$	{equations 11 & 10} $L_S = 0.57\, n_d\, D\, P^*\, M_V$ $\leq 5.9D^2 h_{le} W_l$	{equations 12 & 13} $L_S = 0.0063\, W_l\, (\pi/4) D^2$ $\leq P\, V_V\, M_V\, S/(RT)$ 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 14} $L_P = \left(\frac{PV_V}{RT}\right) M_V S$, where V_V and S are evaluated as shown below:

Fixed-Roof Tanks	Floating-Roof Tanks		
{equation 7} $V_V = H_{VO}\, (\pi\, D^2/4)$	{equation 6} $V_V = (h_v)(\pi\, D^2/4)$)		
	Full Liquid Heel	Partial Liquid Heel	Drain-Dry Tanks
Initial vapor space purge upon commencing forced ventilation (Section 5):			
{equations 15-17} $S = \frac{0.5 n_d + 1}{6}$ ≥ 0.25 ≤ 0.5	{equation 18; Table 6} IFRT $S = 0.6$ EFRT S is taken as $C_{sf} S =$ $0.6 \left(1 - \frac{\frac{0.57 DP^* RT}{PV_V} - K_E K_S}{K_E K_S + 0.6}\right)$	{equation 18; Table 6} IFRT $S = 0.5$ EFRT S is taken as $C_{sf} S =$ $0.5 \left(1 - \frac{\frac{0.57 DP^* RT}{PV_V} - K_E K_S}{K_E K_S + 0.5}\right)$	{Table 6} $S = 0$
Subsequent vapor space purge emissions during the daily cleaning cycle, after standing idle overnight (Section 6):			
$S = 0.25$	$S = 0.6$	$S = 0.5$	$S = 0.5$

Sludge Removal Emissions (Section 6) applicable to all tank types – {continued forced ventilation of the vapor space after the vapor space purge, for each day of the daily cleaning cycle}

vapor concentration method	{equations 19 & 21} $L_{SR} = 60\, Q_v\, n_{SR}\, t_v\, C_V \frac{P_a M_V}{RT}$ where: $C_V \leq P/P_a$	{equation 10} when a liquid heel is present: $L_{SR} \leq 5.9D^2 h_{le} W_l$	{equation 22} if drain-dry, or after the liquid heel has been vacuumed out: $L_{SR} \leq 0.49\, F_e\, D^2\, d_s\, W_l$

Refilling Emissions (Section 7)

{equation 23} $L_F = \left(\frac{PV_V}{RT}\right) M_V S$, 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 19.1) Thus $L_F = 0$	{equation 6} $V_V = (h_v)(\pi\, D^2/4)$

1. INTRODUCTION

This report provides guidance for estimating emissions that result from 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 the tank cleaning process. This report 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 the tank cleaning process. It does not address emissions that may result from the handling of liquids or sludge after such materials have been removed from the tank.

Tank cleaning is a non-routine event for which there are presently no emission factors. 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 report 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 report is not a guide for entering and cleaning storage tanks. Such procedures are addressed in API Standard 2015 [4] and API Recommended Practice 2016. [5]

THIS REPORT DOES NOT UNDERTAKE TO MEET THE DUTIES OF EMPLOYERS, MANUFACTURERS, OR SUPPLIERS TO WARN AND PROPERLY TRAIN AND EQUIP THEIR EMPLOYEES, AND OTHERS EXPOSED, CONCERNING HEALTH AND SAFETY RISKS AND PRECAUTIONS, NOR UNDERTAKE THEIR OBLIGATIONS UNDER LOCAL, STATE, OR FEDERAL LAWS.

2. NOMENCLATURE

This report uses the nomenclature defined in the API Landing Loss Report.[6] Certain additional terms are introduced in this report.

Table 2—Nomenclature

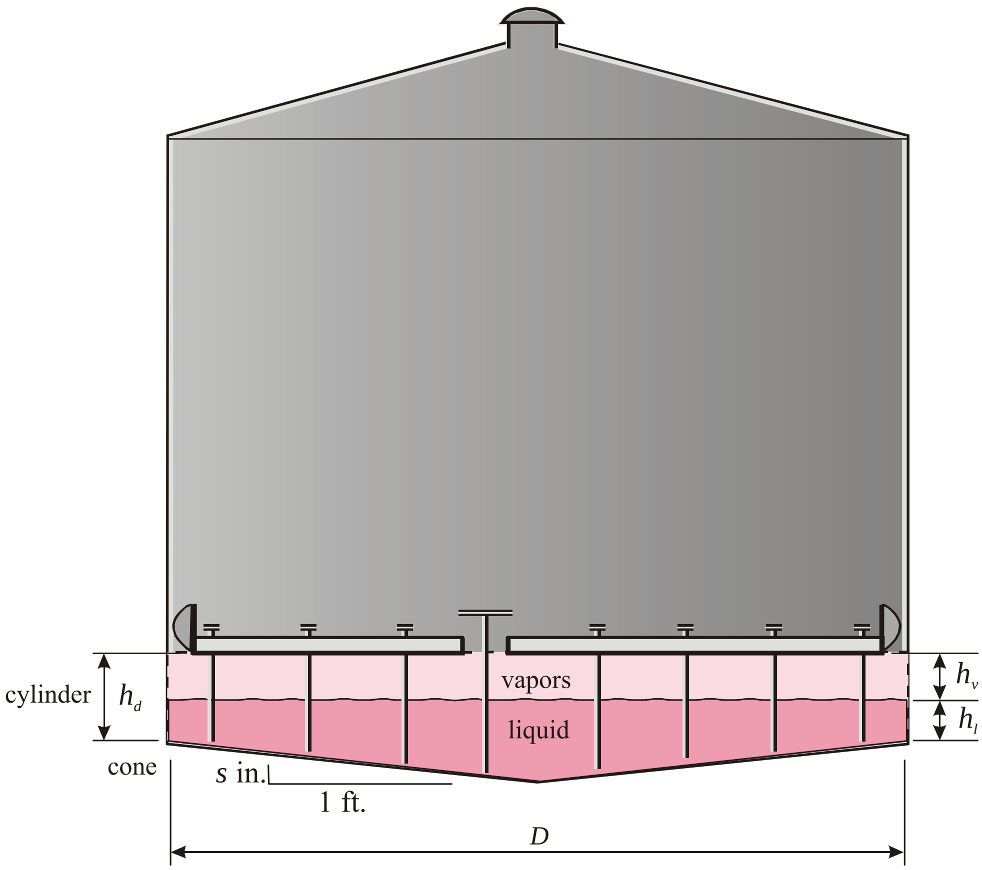
Symbol	Description	Units	Value / Source
B	is a constant from the two-constant form of Antoine's equation	in degrees Rankine;	from Table 3
C_V	is the average vapor concentration by volume during sludge removal	(dimensionless);	as determined from Eqn. 20 in 6.2
D	is the tank diameter	in feet;	as specified 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.1)
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 Fig. 2
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 Fig. 2
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 4
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_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 4; see Fig. 2
H_{VO}	is the fixed-roof tank vapor space outage	in feet;	$= H_S - h_l + H_{RO}$ (1)
K_E	is the vapor space expansion factor	(dimensionless);	$= \dfrac{\Delta T_V}{T}\left(1 + \dfrac{0.50\,B\,P}{T\,(P_a - P)}\right)$ (2) see API 19.1[7] for alternative equations for K_E
K_S	is the standing idle saturation factor	(dimensionless);	[floating-roof tanks] $= \dfrac{1}{1 + 0.053\,P\,(h_v)} \le S$ (3)
L_C	is the total tank cleaning emissions	in pounds;	$= L_S + L_P + L_{SR} + L_F$ (4)
L_F	is the filling loss per cleaning	in pounds;	as calculated per Section 7

L_P	is the vapor 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	
L_{SR}	is the sludge removal loss per cleaning	in pounds;	as calculated per Section 6	
M_V	is the stock vapor molecular weight	in pounds per pound-mole;	as specified by the user or Table 3	
n_c	is the number of air changes per unit time during sludge removal	in hour^{-1};	as specified by the user	
n_d	is the time the tank stands idle	in days;	as specified by the user	
n_{SR}	is the time for sludge removal	in days;	as specified by the user	
P	is the true vapor pressure of the exposed volatile material in the tank	in psia;	as specified by the user or Table 3	
P_a	is the atmospheric pressure at the tank location	in psia;	as specified by the user	
P^*	is a vapor pressure function	(dimensionless);	$= \dfrac{P/P_a}{\left(1+\left[1-\left(P/P_a\right)\right]^{0.5}\right)^2}$	(5)
Q_v	is the ventilation rate during sludge removal	in feet^3/minute;	as specified by the user	
R	is the ideal gas constant	in psia ft^3 per lb-mole ^{o}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 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	
S	is the filling saturation factor	(dimensionless);	as stipulated in Table 1	
t_v	is the daily period of forced ventilation	in hours (per day)	as specified by the user	
ΔT_V	is the daily vapor temperature range[8]	in degrees Rankine;	$= 0.72(T_{MAX} - T_{MIN}) + 0.028\alpha I$, or = 20^{o}F (= 20^{o}R) if unknown	
T	is the average temperature of the vapor space	in degrees Rankine;	= avg ambient temp (^{o}F) + 459.7	
V_V	is the volume of the vapor space	in feet^3;	$= (h_v)\pi D^2/4$ [floating-roof tanks] $= (H_{VO})\pi D^2/4$ [fixed-roof tanks]	(6) (7)
W_l	is the stock liquid density	in pounds per gallon;	as specified by the user or Table 3	

Table 3—Typical* Properties of Selected Petroleum Stocks

	W_l	M_V	A	B	True Vapor Press, P (psia), at Selected Temp's (°F)					
Petroleum Stock	lb/gal	lb/lb-mole	dim'less	°R	40	50	60	70	80	90
Motor Gasoline (RVP 13)	5.6	62	11.644	5043.6	4.7	5.7	6.9	8.3	9.9	11.7
Motor Gasoline (RVP 10)	5.6	66	11.724	5237.3	3.4	4.2	5.2	6.2	7.4	8.8
Motor Gasoline (RVP 7)	5.6	68	11.833	5500.6	2.3	2.9	3.5	4.3	5.2	6.2
Crude Oil (RVP 5)	7.1	50	11.263	5303.9	1.9	2.4	2.9	3.5	4.2	5.0
Jet Naphtha (JP-4)	6.4	80	11.368	5784.3	0.8	1.0	1.3	1.6	1.9	2.4
Jet Kerosene(Jet A)	7.0	130	12.390	8933	0.004	0.006	0.008	0.011	0.015	0.021
Distillate Fuel Oil No.2	7.1	130	12.101	8907	0.003	0.005	0.007	0.009	0.012	0.016

Source: U.S. EPA Report AP-42, Fifth Edition, Supplement D,[9] Table 7.1-2; except the Antoine's equation constants, *A* and *B*, are from API *MPMS* 19.2.[10]
* These are suggested values to be used in the absence of actual data.



Effective height of the cone-down bottom:

$$\frac{1}{3}\left(s\frac{D}{2}\frac{1\text{ ft.}}{12\text{ in.}}\right) = \left(\frac{sD}{72}\right)$$

Figure 2—Height of the Vapor Space under a Landed Floating Roof

Table 4—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 ft); positive for cone down, negative for cone up.	$h_v = \left(h_d + \frac{sD}{72}\right) - h_{le}$ (8)
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_{le} = the height that would result from spreading the available volatile materials evenly over a flat tank bottom. $h_{le} = \frac{(\text{volume of heel, ft}^3)}{(\pi D^2/4)} + \text{clingage}$	$h_v = \left(h_d + \frac{sD}{72}\right) - \left(\frac{\text{volume of heel, ft}^3}{\pi D^2/4}\right) + \left(\frac{0.01\text{ in.}}{12\text{ in./ft}}\right)$
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.	$h_v = h_d - h_{le}$ $\{= h_d - h_l$, given $s = 0\}$

3. OVERVIEW

Storage tanks are cleaned periodically for purposes such as:

a) inspecting the tank bottom or floating roof,

b) preparing the tank for repairs or modifications,

c) removing sediment that may have accumulated at the bottom of the tank, or

d) changing tank service to a stock liquid incompatible with the previous service.

Cleaning a tank involves removing materials from the bottom of the tank. The materials to be removed may include free-standing stock liquid as well as sludge (*i.e.*, stock liquid mixed with residue and water). The steps in cleaning a tank may be characterized as follows: [11]

1) Removal Using Fixed Connections. This involves removal of materials through the fixed connections of the tank, such as pumping through the regular outlet line, or by pumping or suction through other connections, such as a water draw off line or a stripper valve. This removal occurs prior to opening a shell manhole or otherwise creating an opening through the shell of the tank.

2) Removal From Outside an Opened Tank. This involves utilizing an open manhole or other opening through the tank shell to remove materials from the tank bottom by means of a suction pump or vacuum truck, with personnel remaining outside the tank.

3) Removal From Inside the Tank. This involves entry by workers to remove remaining materials from the tank bottom.

For purposes of estimating emissions, these steps may be further broken down as follows (Activities without significant associated emissions, such as setting a floating roof on high legs or isolating the tank, are not addressed in this summary. Furthermore, for any given tank cleaning scenario, the steps that actually take place and the order in which they occur may vary.):

TANK CLEANING STEPS	COMMENTS CONCERNING EMISSIONS
1) Removal Using Fixed Connections. a) Normal Pumpout. As much stock liquid as possible is pumped out through the tank outlet in the normal manner (*i.e.*, until the liquid level has dropped below the open end of the outlet line, and no more liquid moves through the outlet). b) Standing Idle. The tank may remain in the condition resulting from normal pumpout for some period of time until the next step begins. This condition will typically involve a full or partial heel of stock liquid remaining in the bottom of the tank.	Normal pumpout and standing idle may occur simply due to emptying the tank. These steps are not, then, unique to tank cleaning. Methods for estimating emissions from these two steps are presented in other API publications.[12, 13]
	Removal of all free-standing stock liquid is sometimes referred to as *completely emptying* or *stripping*, with *cleaning* designating the removal of sludge (defined as stock liquid mixed with residue and water).[14] For purposes of this report, however, any removal of materials from the tank bottom by means other than normal pumpout shall be included as a step in the tank cleaning process, regardless of whether or not the removed material is recoverable stock liquid.

c) <u>Suction/Vacuum through Fixed Connections</u>. The removal of additional material may be achieved by the use of a suction pump or vacuum truck connected to a fixed connection, such as the water draw off line. i. Removal may be facilitated by floating the tank bottom materials on water or fuel oil that has been pumped into the tank. ii. Removal of heavier tank bottom materials may be facilitated by means such as solvents, special diluents and chemicals, heating, circulation, or agitation.	During removal of material by suction or vacuum, the rate of withdrawal may not result in an appreciable rate of change in the height of the vapor space. These removal activities may also involve downtime, such as for achieving tank isolation. From an emissions perspective, then, the tank may be considered to be in a *standing idle* condition during this stage of removal activities as long as there is no forced ventilation involved. When forced ventilation (such as by eductors mounted on the top of the tank) is involved, then the air changes achieved by the forced ventilation must be accounted for (as *sludge removal*, even though the material removed may be largely recoverable stock liquid – see the discussion of the three stages of removal activities under 'Removal from Outside an Opened Tank). The primary condition that changes during this stage is the nature of the exposed surface. The initial condition may be a heel of free-standing stock liquid. As the free-standing stock liquid is removed, however, sludge becomes exposed. **NOTE:** If a vacuum truck or suction pump is used, the pump used to create the vacuum may expel vapors to the atmosphere. This report addresses only emissions from the tank, and does not address emissions that may be expelled by a vacuum pump used in the tank cleaning process.
2) <u>Removal From Outside an Opened Tank</u>. A shell manhole or cleanout fitting is opened to serve as an inlet for the flow of fresh air, as well as to provide access to the tank bottom for further removal of stock liquid or sludge. Workers do not enter the tank during this stage of removal activities. a) <u>Vapor Space Purge</u>: Whenever a shell manhole (or other shell fitting) is opened, the tank is immediately ventilated (typically by means of an eductor located at the top of the tank, and subsequently by fans or blowers mounted on shell openings). b) <u>Suction/Vacuum through Shell Openings</u>. A vacuum hose is inserted through the open manhole (or other shell opening) to remove additional materials. i. Another hose may be inserted through the shell opening to apply chemicals, fuel oil or a jet stream of water or steam in order to dislodge heavy materials. ii. Mechanical robotic cleaning devices may be used inside the tank (such as for carrying the ends of the hoses to specific locations).	Vapors generated during removal of materials from an opened tank are expelled from the tank by forced ventilation. Although some free-standing stock liquid may be removed during this stage, ventilated removal of materials from an opened tank shall be deemed *sludge removal* for purposes of this report. As with removal through fixed connections, removal activities through an open manhole may be subject to periods of downtime. If the tank is closed (*i.e.*, the cover replaced on the shell manhole that had been opened) during such downtimes, then the forced ventilation may also be discontinued (so as to avoid creating a negative internal pressure that could collapse the tank). From an emissions perspective, the tank is considered to be in a *standing idle* condition during such non-ventilated downtime periods. When the tank is reopened to resume removal activities, the first air change achieved by the resumption of ventilation will *purge the vapor space* of vapors that had accumulated during the standing idle period. Removal activities from outside an opened tank may be characterized by the following three scenarios: – Sludge removal (with forced ventilation) – Standing Idle (without forced ventilation) – Vapor Space Purge (after a period of standing idle without forced ventilation) See the note at 'Suction/Vacuum through Fixed Connections" concerning emissions from a vacuum truck or suction pump.

3) <u>Removal From Inside the Tank</u>. a) Sludge Removal: Workers enter the tank to remove any remaining sludge. i. Water, fuel oil or approved chemicals may be used to wash down the material to be removed. b) Vapor Space Purge: After any period (such as overnight) during which removal activities have ceased, forced ventilation is resumed prior to workers reentering the tank.	Although this stage involves workers entering the tank, the potential scenarios from an emissions perspective are the same as for removal activities from outside an opened tank: – Sludge removal (with forced ventilation) – Standing Idle (without forced ventilation) – Vapor Space Purge (after a period of standing idle without forced ventilation) The primary change in condition continues to be the nature of the exposed surface, and thus the properties of the materials being removed.

For purposes of estimating emissions, then, tank cleaning may be characterized as comprising the following steps:

a) Normal Pumpout: As much stock liquid as possible is pumped out through the tank outlet in the normal manner (*i.e.*, until the liquid level has dropped below the open end of the outlet line, and no more liquid moves through the outlet). [If the tank has a floating roof, the floating roof will have landed on its legs and its vacuum breaker vent will have opened, causing air to be drawn into the space beneath the floating roof. Prior to emptying the tank for cleaning, the floating roof legs are usually placed in the high leg position (typically about 6 ft) to maximize the space available for workmen under the floating roof.]

   As the liquid level drops during normal pumpout, flow of air through the tank vents is from outside the tank to inside the tank. Given this inward direction of air flow, it is assumed that no emissions occur during normal pumpout.

b) Standing Idle: The tank may remain in the condition resulting from normal pumpout for some period of time until the next step begins. This condition will typically involve a full or partial heel of stock liquid remaining in the bottom of the tank.

   The defining characteristics of the standing idle condition are:

   – volatile material, capable of generating vapors, remains in the tank (as a full or partial liquid heel, or as clingage on the tank bottom),

   – the height of the vapor space is reasonably constant (change is limited to stripping of the liquid heel, or pumping in of diluent) during the period in question, and

   – there is no forced ventilation of the vapor space (*i.e.*, no eductors, fans, or blowers are engaged in expelling vapors from the tank).

   During a standing idle period, vapors are generated inside the tank by evaporation of the remaining volatile material. The diurnal temperature cycle causes expansion and contraction of the air/hydrocarbon mixture (*i.e.*, vapors) in the tank, thereby causing some of these vapors to be expelled from the tank. For an external floating-roof tank, these vapor losses may be further driven by wind action.

c) Vapor Space Purge: When eductors, fans, or blowers are started up, either at the top of the tank or at a shell manhole, cleanout fitting or other shell fitting, the first air change is deemed to expel those vapors that remain from the prior stage of the tank cleaning process. This constitutes a purge of vapors from the tank. Emissions associated with subsequent air changes are accounted for under sludge removal.

A vapor space purge will occur each time that ventilation commences after a period of standing idle without ventilation.

d) Sludge Removal: As used in this report, sludge removal refers to the removal of volatile materials from a tank while the tank is subject to forced ventilation.

Volatile materials evaporate during sludge removal, thereby producing vapors that are expelled from the tank by the eductors, fans, or blowers. When sludge removal activities are intermittently interrupted and forced ventilation is discontinued, such as during the overnight period, then the tank cleaning process follows the cycle illustrated in Figure 1.

In addition to the preceding steps, the following steps (that occur subsequent to tank cleaning) should be considered in the estimate of tank cleaning emissions:

e) Remain Clean: Once the tank has been cleaned, it may remain in the clean condition for some period of time.

In that there are no remaining sources of vapors once the tank has been cleaned, no further emissions will occur for as long as the tank remains clean.

f) Refilling: The clean tank is refilled.

The incoming stock liquid generates vapors, which are then displaced from the tank as the stock liquid level rises. [If the tank has a floating roof, the incoming stock liquid displaces vapors from under the floating roof until the stock liquid level is high enough to float the roof off its legs, closing the vacuum breaker vent.]

The *normal pumpout* and *remain clean* steps do not involve emissions. The total tank cleaning emissions (L_C) are therefore:

$$L_C = L_S + L_P + L_{SR} + L_F \tag{4}$$

where:

L_S = standing idle emissions,

L_P = vapor space purge emissions,

L_{SR} = sludge removal emissions, and

L_F = refilling emissions.

Methods for estimating emissions from the *standing idle* and *refilling* steps for floating-roof tanks are given in the API Landing Loss Report.[15] The *standing idle* and *refilling* emissions for fixed-roof tanks are estimated as normal standing storage (breathing) and working (filling) losses, as specified in Chapter 19.1 [16] of the API *Manual of Petroleum Measurement Standards* [API 19.1]. This report provides guidance for applying these methods to the standing idle and refilling steps as they pertain to tank cleaning. Guidance for estimating emissions from the other two steps, *vapor space purge* and *sludge removal*, is also given in this report.

While the steps involved in the tank cleaning process may vary considerably across the industry, these steps may be reasonably summarized by the flow diagram in Figure 3, for purposes of estimating emissions.

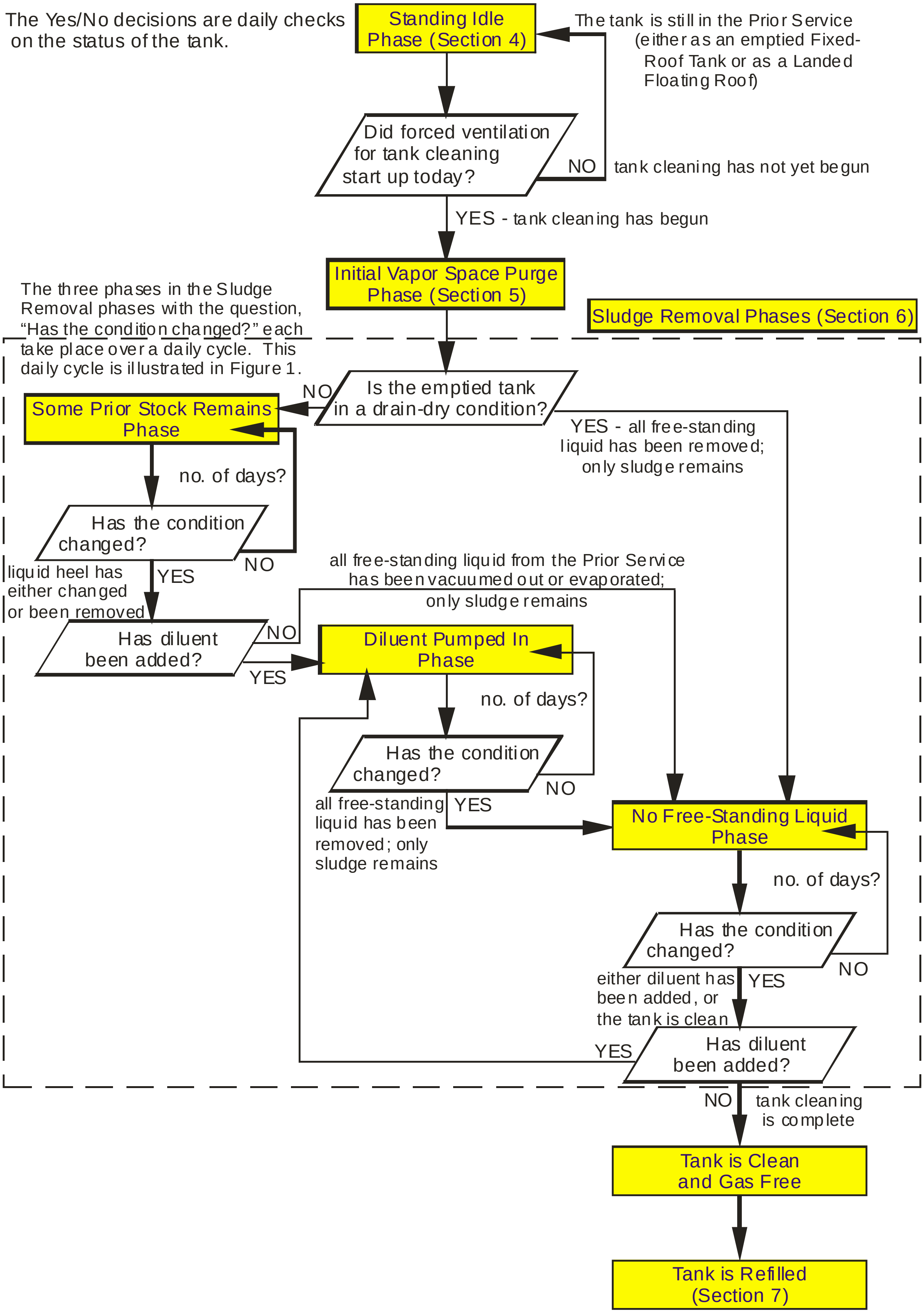


Figure 3—Flow Diagram of Tank Cleaning Tasks

4. STANDING IDLE EMISSIONS

The *standing idle* step 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 Sections 4.1 and 4.2.

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

4.1 Fixed-Roof Tanks

The *standing idle* emissions for fixed-roof tanks are estimated as normal standing storage (breathing) losses, as specified in API 19.1.[17] If this standing idle time is included in the number of days that the tank is considered to be in service for estimating normal standing storage losses, then it should not be included with the estimate of tank cleaning emissions. Thus:

L_S = 0, for fixed-roof tanks.

4.2 Floating-Roof Tanks

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 the API Landing Loss Report.[18] This method is outlined below.

4.2.1 Internal Floating-Roof Tanks with a Full or Partial Liquid Heel

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

$$L_S = n_d K_E \left(\frac{P V_V}{RT} \right) M_V K_S \tag{9}$$

limited by:

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

$$L_S \le 5.9 D^2 h_{le} W_l \tag{10}$$

where:

n_d = the time that the tank stands idle (days),

K_E = vapor space expansion factor (dimensionless),[19]

$$= \frac{\Delta T_V}{T} \left(1 + \frac{0.50\, BP}{T(P_a - P)} \right) \tag{2}$$

(see API 19.1[20] for alternative equations for K_E)

P = the true vapor pressure of the exposed volatile material in the tank (psia),

V_V = volume (ft^3) of the vapor space under the floating roof,

$$= (h_v)(\pi D^2/4), \tag{6}$$

h_v = the height (ft) of the vapor space under the floating roof for the given standing idle period (see Table 4),

D = the tank diameter (feet),

R = the ideal gas constant (psia ft^3 per lb-mole ^{o}R),
= 10.731 psia ft^3 per lb-mole ^{o}R,

T = the average temperature of the vapor space (^{o}R),
= the average ambient temperature (^{o}R)
[Note: The heel of liquid is between the vapor space (which would likely have a higher temperature than ambient air) and the ground (which would likely have a lower temperature than ambient air), and thus may be reasonably represented by the average ambient air temperature.]

M_V = the stock vapor molecular weight (lb/lb-mole),

K_S = the standing idle saturation factor (dimensionless),

$$= \frac{1}{1 + 0.053\, P\, (h_v)} \leq S \quad \text{(where S equals 0.6 for a full heel and 0.5 for a partial heel)} \qquad (3)$$

h_{le} = the effective height (ft) of the stock liquid and sludge for the given standing idle period (see Table 4), and

W_l = the stock liquid density (lb/gallon).

4.2.2 External Floating-Roof Tanks with a Full or Partial Liquid Heel

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

$$L_S = 0.57\, n_d\, D\, P^*\, M_V \qquad (11)$$

limited by:

$$L_S \leq 5.9 D^2\, h_{le}\, W_l \qquad (10)$$

where:

$$P^* = \frac{P / P_a}{\left(1 + \left[1 - \left(P / P_a\right)\right]^{0.5}\right)^2} \qquad (5)$$

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

The other variables are evaluated as above.

4.2.3 Drain Dry Floating-Roof Tanks

As discussed in the API Landing Loss Report,[21] 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:

$$L_S = 0.0063\, W_l\, (\pi/4) D^2 \qquad (12)$$

limited by :

$$L_S \leq P\, V_V\, M_V\, S / (RT) \qquad (13)$$

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

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. Preparing the tank for sludge removal, however, involves the use of forced ventilation in order to flush out these remaining vapors. *Forced ventilation*, as used in this report, refers to any expulsion of vapors from a tank by means of eductors, fans, or blowers, 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:

$$L_P = \left(\frac{PV_V}{RT}\right) M_V S \qquad (14)$$

where:

P = the true vapor pressure of the exposed volatile material in the tank (psia),

V_V = volume (ft^3) of the vapor space,

R = the ideal gas constant (psia ft^3 per lb-mole ^oR),
= 10.731 psia ft^3 per lb-mole ^oR,

T = the average temperature of the vapor space (^oR),
= the average ambient temperature (^oR),

M_V = the stock vapor molecular weight (lb/lb-mole),

S is evaluated as follows (see discussion below for the determination of these values):

Table 5—Summary of Saturation Factors (*S*) for Vapor Space Purge

Fixed-Roof Tanks	Floating-Roof Tanks: Full Liquid Heel	Floating-Roof Tanks: Partial Liquid Heel	Floating-Roof Tanks: Drain-Dry Tanks
Initial vapor space purge upon commencing forced ventilation (Section 5):			
{equations 15-17} $S = \frac{0.5 n_d + 1}{6}$ ≥ 0.25 ≤ 0.5	{equation 18; Table 6} IFRT $S = 0.6$ EFRT S is taken as $C_{sf}S$ = $0.6\left(1 - \frac{\frac{0.57DP*RT}{PV_V} - K_E K_S}{K_E K_S + 0.6}\right)$	{equation 18; Table 6} IFRT $S = 0.5$ EFRT S is taken as $C_{sf}S$ = $0.5\left(1 - \frac{\frac{0.57DP*RT}{PV_V} - K_E K_S}{K_E K_S + 0.5}\right)$	{Table 6} $S = 0$
Subsequent vapor space purge emissions during the daily cleaning cycle, after standing idle overnight (Section 6):			
$S = 0.25$	$S = 0.6$	$S = 0.5$	$S = 0.5$

This corresponds 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 Sections 5.1 and 5.2. Emissions associated with subsequent air changes are accounted for as sludge removal 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 during sludge removal, then the emissions from the next morning's vapor space purge (first air change) are estimated as described in Figure 4 of Section 6. As with the initial vapor space purge, emissions from subsequent air changes following these daily vapor space purges are accounted for as sludge removal emissions.

5.1 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:

$$V_V = H_{VO}(\pi D^2/4) \tag{7}$$

where:

H_{VO} = the fixed-roof tank vapor space outage (ft)[22]

$$H_{VO} = H_S - h_l + H_{RO} \tag{1}$$

where:

H_S = the height of the tank shell (ft),

h_l = the height of the stock liquid and sludge above the tank bottom at the tank shell (ft), and

H_{RO} = the roof outage (the effective height of the vapor space enclosed by the tank roof, ft)

= $s_r D/72$ for a cone-shaped roof, where s_r 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 19.1.[23]

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

where:

N = turnover rate (year^{-1})

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):

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

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).

$$S = \frac{0.5\,n_d + 1}{6} \tag{15}$$

For periods of less than one day, 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 internal floating-roof tank (IFRT) with a partial heel may be reasonably chosen as an upper bound. This is equal to 0.5, as shown in Table 6. 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 19.1,[24] 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 the 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 generated vapors would be less concentrated in a larger vapor space.

These limits are expressed as follows:

$$S \geq 0.25 \tag{16}$$

$$S \leq 0.5 \tag{17}$$

5.2 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:

V_V = volume (ft^3) of the vapor space under the floating roof,

$$= (h_v)\,(\pi\, D^2/4), \tag{6}$$

where:

h_v = the height (ft) of the vapor space under the floating roof for the given vapor space purge (see Table 4)

The saturation factor (S) is evaluated as specified for the filling saturation factor in the API Landing Loss Report.[25] 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 internal floating-roof tank with a full liquid heel may be attributable to the incoming liquid – the 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 6. The factors for external floating-roof tanks given in Table 6 are determined from the $C_{sf}S$ term given in the API Landing Loss Report Table 1:[26]

$$C_{sf}\,S = \left(1 - \frac{0.57 n_d DP^* M_V - n_d K_E (PV_V / RT) M_V K_S}{n_d K_E (PV_V / RT) M_V K_S + (PV_V / RT) M_V S}\right) S$$

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

$$C_{sf}\,S = \left(1 - \frac{0.57 DP^* (RT / PV_V) - K_E K_S}{K_E K_S + S}\right) S \tag{18}$$

Table 6—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 14	
Full liquid heel		
Internal floating-roof tank (IFRT)	0.6	
External floating-roof tank (EFRT)	$0.6\left(1-\dfrac{\dfrac{0.57DP^*RT}{PV_V}-K_EK_S}{K_EK_S+0.6}\right)$	
Partial liquid heel		
Internal floating-roof tank (IFRT)	0.5	
External floating-roof tank (EFRT)	$0.5\left(1-\dfrac{\dfrac{0.57DP^*RT}{PV_V}-K_EK_S}{K_EK_S+0.5}\right)$	
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. SLUDGE REMOVAL EMISSIONS

6.1 Overview of Methodology

The calculation of *vapor space purge* emissions accounted for the vapors that were expelled by the first air change of the vapor space upon commencing forced ventilation at the end of a standing idle period. There still may be volatile materials remaining in the tank, however, that will continue to evaporate and generate vapors. These additional vapors are accounted for as the *sludge removal* emissions, and they are expelled by continued forced ventilation, subsequent to the vapor space purge (*i.e.*, after the first air change of the vapor space).

The volatility of the remaining materials, however, may be much less than the volatility of the previously stored stock liquid. An appropriate judgment should be made in assigning properties to the sludge. For example, it may be appropriate, when characterizing the properties of sludge in a gasoline tank, to apply the properties of a less volatile stock – such as diesel fuel.

Three methods were considered for estimating sludge removal 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 Appendix A, where the other methods are discussed and compared to the vapor concentration method.

The vapor concentration method estimates sludge removal emissions from the average vapor concentration in the vapor space (usually reported as a percent of the lower explosive limit, or %LEL), the ventilation rate, and the length of time required for sludge removal. These parameters are often known since they are 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 7.

Table 7—LEL Values for Selected Compounds

Stock	LEL[27] (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, 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 Appendix 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 this case, it is conservative to use the monitor's minimum detection level as the %LEL for determining the vapor concentration.

The mass of vapors that escape the tank during sludge removal is the product of the average density of the hydrocarbon vapors, the average ventilation rate, and the length of time over which the sludge is removed. The vapor concentration and ventilation rate may vary during sludge removal (for example, fans may not be operated continuously at a constant rate), but using the average concentration and ventilation rate accounts for this.

When sludge removal activities are intermittently interrupted and forced ventilation is discontinued, 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). In such cases, the initial standing idle and vapor space purge emissions are estimated as shown in Sections 4 and 5, respectively. Emissions from subsequent standing idle periods, for which the standing idle time is limited to an overnight cessation of operations during sludge removal, 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 external floating-roof tanks. In other words, C_{sf} should be taken as 1.0 for vapor space purges during the daily tank cleaning cycle, with the result that the saturation level for external floating-roof tanks shall be taken as equal to the saturation level for internal floating-roof tanks.

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. When the prior stock was a relatively volatile liquid, such as gasoline, each of these sludge removal methods might be characterized as a less volatile stock, due to the preferential evaporative loss of the lighter ends from the remaining sludge. The scenario of circulated diluent would be characterized by the properties of the diluent.

In the case of dislodging the sludge with a stream of water or a squeegee or shovel, there would 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. As noted above, however, the properties of the sludge may be represented 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 Section 5.2, 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 Section 5.1, for periods of less than one 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.

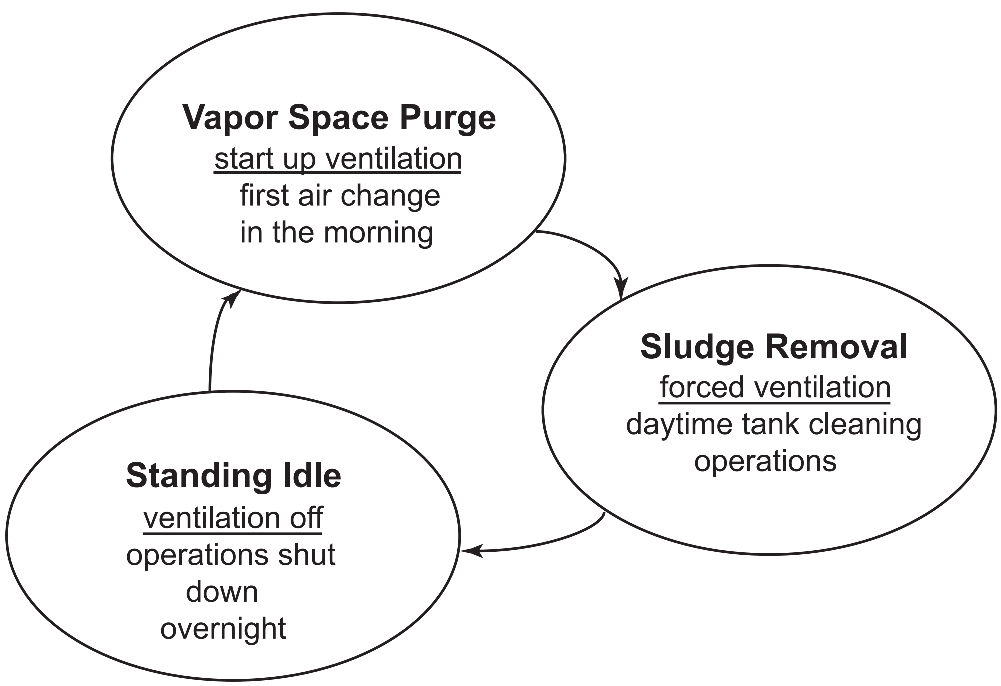
The scenarios to be considered in the estimation of emissions during the daily tank cleaning cycle are summarized in Figure 4.

Vapor Space Purge (per day)

{equation 14}

$L_P = \left(\frac{PV_V}{RT}\right) M_V S$, where V_V and S are evaluated as shown below:

Fixed-Roof Tanks	Floating-Roof Tanks		
{equation 7}	{equation 6}		
$V_V = H_{VO} (\pi D^2/4)$	$V_V = (h_v)(\pi D^2/4)$)		
	Full Liquid Heel	Partial Liquid Heel	No Free-Standing Liquid
$S = 0.25$	$S = 0.6$	$S = 0.5$	$S = 0.5$



Standing Idle

All Tanks

$L_S = 0$

(overnight standing idle evaporation is accounted for with the next morning's vapor space purge)

Sludge Removal {equations 19, 21, 10, & 22}

All tanks:	$L_{SR} = 60 Q_v n_{SR} t_v C_V \frac{P_a M_V}{RT}$
Limit on concentration:	$C_V \leq P/Pa$
When a liquid heel is present:	$L_{SR} \leq 5.9 D^2 h_{le} W_l$
After all free-standing liquid has been removed:	$L_{SR} \leq 0.49 F_e D^2 d_s W_l$

Figure 4—Equations of the Daily Tank Cleaning Cycle

6.2 Derivation of the Vapor Concentration Method Equations

The vapor concentration (C_V), determined from the %LEL, 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:

P_T = the total system pressure (which, for an opened tank, is approximately atmospheric pressure)

P_T = P_a

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, and thus:

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

Recognizing that density is weight divided by volume:

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

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

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

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

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

Therefore, the sludge removal emissions (L_{SR}) estimated by the vapor concentration method are:

$$L_{SR} = (60\ \text{min/hr})(Q_v\ \text{ft}^3/\text{min})(n_{SR}\ \text{day})(t_v\ \text{hr/day})\, C_V \frac{(P_a\ \text{psia})(M_V\ \text{lb/lb}\cdot\text{mole})}{(R\ \text{psia ft}^3/\text{lb}\cdot\text{mole}^\circ\text{R})(T\ ^\circ\text{R})}$$

$$L_{SR} = 60 Q_v n_{SR} t_v C_V \frac{P_a M_V}{RT} \qquad (19)$$

where:

Q_v = average ventilation rate (ft^3/min) during sludge removal [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[28] specifies a minimum of 5 air changes per hour.],

n_{SR} = the time for sludge removal (days),

t_v = the daily period of forced ventilation (hr/day) [Note: Do not include the time for the vapor space purge. At 5 air changes per hour, this would be 0.2 hours.],

C_V = average vapor concentration by volume during sludge removal

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

RF = response factor (dimensionless)

= 1.0 if unknown [Note: See Appendix B for a discussion of LEL measurements and response factors.],

P_a = atmospheric pressure at the tank location (psia),

M_V = stock vapor molecular weight (lb/lb-mole),

R = ideal gas constant

= 10.731 psia-ft^3/(lb-mole ^{o}R),

T = average temperature of the vapor and liquid below the floating roof (^{o}R),

= the average ambient temperature (^{o}R), and

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:

$$C_V \leq P/P_a \qquad (21)$$

where:

P = the true vapor pressure of the exposed volatile material in the tank (psia).

The estimate of sludge removal 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:

$$L_S \leq 5.9 D^2 h_{le} W_l \qquad (10)$$

where:

D = the tank diameter (feet),

h_{le} = the effective height (ft) of the stock liquid and sludge for the given sludge removal period (see Table 4),

W_l = the density of the stock liquid (pounds per gallon), and

the constant, 5.9, has units of gal/ft^3 (the product of the constant term π/4 and the conversion factor 7.48 gal/ft^3).

Once the free-standing stock liquid has been vacuumed out (or drained out, in the case of a drain-dry tank), however, much of the remaining sludge consists of relatively non-volatile residue. The upper limit on emissions from the vacuumed-out condition may assume that 20% of the sludge is volatile (per the Sludge Volume Method described in A.1). This limit is expressed as follows:

$$L_{SR} \leq (\pi/4)(D \text{ ft})^2 F_e (d_s \text{ in.})(W_l \text{ lb/gal})(\text{ft/12 in.})(7.48 \text{ gal/ft}^3)$$

$$L_{SR} \leq 0.49 F_e D^2 d_s W_l \qquad (22)$$

where:

F_e = the fraction of the sludge that evaporates (= 0.20 if unknown, from A.1),

d_s = the average depth of sludge (inches),

the constant, 0.49, has units of gal/(in. ft^2), and the other terms are defined as shown above.

7. REFILLING EMISSIONS

A method for estimating the emissions that result from refilling a drain dry floating-roof tank is presented in the API Landing Loss Report.[29] This method recognizes that the vapors generated during the standing idle period in a drain dry tank, including those vapors that may remain in the tank at the time of refilling, are fully accounted for by the calculation procedure used to estimate standing idle loss. The only vapors that are accounted for during the refilling of a drain dry tank, then, are those that are generated by the incoming liquid. This scenario is also true when filling a tank that has been cleaned. The refilling emissions (L_F) may therefore be stated as:

$$L_F = \left(\frac{PV_V}{RT}\right) M_V S \qquad (23)$$

This corresponds to one working-loss (filling) cycle of the vapor space. Differences in evaluation of the variables for fixed- and floating-roof tanks are discussed below.

7.1 Fixed-Roof Tanks

Refilling emissions for fixed-roof tanks are accounted for in the estimate of normal working losses that result from fixed-roof tank throughput, as specified in API 19.1.[30] In that these filling losses are already accounted for, refilling losses are not included in the estimation of tank cleaning emissions for fixed-roof tanks. Thus:

$L_F = 0$ for fixed-roof tanks.

7.2 Floating-Roof Tanks

The volume of the vapor space for estimating filling loss from a floating-roof tank is limited to the space under the floating roof:

V_V = volume of the vapor space (ft^3) under the floating roof, for a clean tank,

$$= (h_v)(\pi D^2/4) \qquad (6)$$

where:

h_v= the height (ft) of the vapor space under the floating roof (see Table 4).

The saturation factor (S) is evaluated as specified in the API Landing Loss Report.[31] In that the tank is in a vapor-free condition prior to the commencement of refilling, the scenario of a drain dry tank would apply:

S = 0.15 (as for a drain dry tank).

The refilling emission estimate given by this method is based on the refilling occurring within one day's time. If the time to float a floating roof off its legs takes more than one day, however, then the estimate should be adjusted to account for breathing losses that may occur due to the diurnal temperature cycle.

8. CONTROLLING EMISSIONS DURING CLEANING

Instead of venting to the atmosphere, vapors from any of the above steps may be sent to a control device (such as a thermal oxidizer or a carbon adsorption bed). If the vapors are controlled at any step, then the emissions calculated by that step should be factored to account for the vapor-reduction efficiency of the control device. For example, if the vapor space purge and sludge removal emissions are sent to a thermal oxidizer with a 95% control efficiency, then the vapor space purge and sludge removal emissions calculated above should be factored by [1 – 0.95] to determine the actual emissions from those steps.

9. EXAMPLE

This example is not meant to be representative of industry practice for cleaning tanks or typical of any particular company’s tank cleaning procedures, but rather is intended only as an illustration of how the calculations are to be performed. The scenario presented may involve more days than are often required to clean a gasoline storage tank, in that multiple phases were included in the example for illustrative purposes.

9.1 Description

Data collection is facilitated by use of the forms in Appendix C. This example is based on the forms having been filled in as shown below.

Company Good Guys Oil Co. Location Tulsa, OK Tank ID No. Tk-4 Diameter 110 ft Tank Height 48 ft Paint Color White Paint Condition (Good or Poor) Good Fixed Roof Type (cone, dome, or open top): Cone If cone-down bottom: bottom slope 0 in./ft Description of tank stock prior to cleaning: Gasoline (RVP 10)	DATA COLLECTION FORM 1 of 5 **STANDING IDLE PHASE** Date the tank was emptied (normal pumpout down to heel): 05 / 11 / 2006 Type of heel (full, partial or drain dry): Full heel If full heel, liquid height at shell 1 ft If partial heel: heel diameter (sump) ______ft liquid height (in sump) _____ft Floating Roof (Y/N) Yes Floating roof leg height 6 ft

Start date – forced ventilation begins: 05 / 13 / 2006 Ventilation rate 4,850 cfm Hours/day of venting 24 hr Average % LEL (of tank headspace or vented stream) 12 % LEL Is ventilation routed to vapor control? (Y/N) No Completion date – this phase: 05 / 14 / 2006	DATA COLLECTION FORM 2 of 5 **SLUDGE REMOVAL PHASE** (with heel of prior stock) Calibration gas Propane LEL of calibration gas 2.1 % Response Factor (if known) not known If heel condition changed since Standing Idle phase, type of heel (full, partial or drain dry): Partial heel If full heel, liquid height at shell _____ft If partial heel: heel diameter (sump) 2 ft liquid height (in sump) 0.5 ft

Start date – flooded with diluent: 05 / 14 / 2006 Ventilation rate 4,850 cfm Hours/day of venting 10 hr Average % LEL (of tank headspace or vented stream) 3.0 % LEL Is ventilation routed to vapor control? (Y/N) No Completion date – this phase: 05 / 16 / 2006	DATA COLLECTION FORM 3 of 5 **SLUDGE REMOVAL PHASE** (with heel of diluent) Calibration gas Propane LEL of calibration gas 2.1 % Response Factor (if known) not known A full liquid heel is assumed while the tank bottom is flooded with diluent. Description of diluent (cutter stock): Kerosene Height of liquid heel at shell 0.5 ft

Start date – only sludge remains (no free-standing liquid): 05 / 16 / 2006 Avg depth of sludge 0.5 inches Ventilation rate 4,850 cfm Hours/day of venting 10 hr Is ventilation routed to vapor control? (Y/N) No Completion date – this phase: 05 / 18 / 2006	DATA COLLECTION FORM 4 of 5 **SLUDGE REMOVAL PHASE** (with sludge only) Calibration gas Propane LEL of calibration gas 2.1 % Response Factor (if known) not known Average % LEL (of tank headspace or vented stream) 1.0 % LEL

Start date – tank refilling: 07 / 10 / 2006 Description of stock for refilling: Gasoline (RVP 10) Are displaced vapors routed to vapor control? (Y/N) No	DATA COLLECTION FORM 5 of 5 **REFILLING PHASE** Completion date – this phase: 07 / 10 / 2006 Hours to refloat the roof (for floating-roof tanks only): 3.5 hr

A narrative summary of the schedule of cleaning activities, as given on the Data Collection Forms, may be stated as follows:

Days 1–2: Standing idle after normal pumpout. During this period, the liquid heel is vacuumed out through the water draw off line.

Day 3: Sludge removal (with prior stock remaining). The tank is degassed by forced ventilation for 24 hours, with only a partial heel of gasoline remaining in the sump.

Days 4–5: Sludge removal (with diluent). Kerosene is pumped in to a depth of 6 inches in order to loosen the sludge, accompanied by vacuuming out of the kerosene/gasoline/sludge mixture. The forced ventilation operates for the 10 hours per day that this circulation of diluent is taking place, but is shut off overnight.

At the end of day 5 the free-standing liquid is pumped out, and approximately one-half inch of kerosene-soaked sludge remains in the bottom of the tank.

Days 6–7: Sludge removal (no free-standing liquid remains). Personnel enter the tank, squeegee out the remaining sludge, and rinse down the tank, leaving it free of volatile material (clean and gas free).

~60 days later. Refilling. At a date approximately two months later, the clean tank is refilled with gasoline.

9.2 Days 1–2 Standing Idle after Normal Pumpout

Emissions during days 1–2 consist of standing idle losses generated by the heel of gasoline in the tank. For internal floating-roof tanks with a liquid heel, the standing idle loss is:

$$L_S = n_d K_E \left(\frac{PV_V}{RT}\right) M_V K_S \tag{9}$$

K_E = vapor space expansion factor,

$$= \frac{\Delta T_V}{T}\left(1 + \frac{0.50\,BP}{T(P_a - P)}\right) \tag{2}$$

First, determine the properties of the stock liquid. These properties are a function of the type of stock and the storage conditions. The storage conditions are a function of the ambient meteorological conditions. Average values for the pertinent meteorological parameters for the month of May in Tulsa, Oklahoma may be obtained from the database in EPA's TANKS program.[32] These values are:

T_{max} = 79.7°F

T_{min} = 58.8°F

T_{avg} = $(T_{max} + T_{min})/2$

= 69.3°F

I = 1,873 Btu/ft^{3}day

P_a = 14.38 psia

The vapor space under the floating roof would be somewhat warmer than the average ambient air temperature, and the ground would be somewhat cooler than the average ambient air temperature. The temperature of a heel of liquid in the bottom of the tank would be expected to be between the temperature of the vapor space and the temperature of the ground, and thus the average ambient air temperature would be a reasonable approximation of the temperature of the liquid heel.

The properties of the gasoline in the liquid heel are then obtained as follows:

T = (69.3 + 459.7)

= 529.0°R

From equation 29 in API 19.1:[33]

$P = \exp[A - B/T]$

Antoine's constants are obtained from Table 3:

A = 11.724

B = 5237.3 °R

And thus:

$$P = \exp[11.724 - (5237.3 / 529.0)]$$
$$= 6.19 \text{ psia}$$

Also, from Table 3:

W_l = 5.6 lb/gal

M_V = 66 lb/lb-mole

And, from equation 25b of API 19.1[34]:

$$\Delta T_V = 0.72(T_{max} - T_{min}) + 0.028\ \alpha\ I$$

For a tank with white paint in good condition, the value of the solar absorptance factor (α) is given in API 19.1[35] Table 5 as 0.17, and thus:

$$\Delta T_V = 0.72(79.7 - 58.8) + 0.028(0.17)(1{,}873)$$
$$= 24.0\ ^{\circ}\text{F}$$

Having obtained values for each of the required variables, the vapor space expansion factor (K_E) may now be calculated:

$$K_E = [24.0/(529.0)]\ \{1 + 0.5\ (5237.3)(6.19)/[(529.0)(14.38 - 6.19)]\}$$
$$= 0.215$$

Next calculate the volume of the vapor space under the floating roof:

$$V_V = (h_v)(\pi\ D^2/4) \quad (6)$$

where (from Table 4, for a full liquid heel):

$$h_v = h_d - h_l$$
$$= 6 \text{ ft} - 1 \text{ ft}$$
$$= 5 \text{ ft}$$

$$V_V = (5 \text{ ft})\ (\pi\ (110 \text{ ft})^2 / 4)$$
$$= 47{,}517 \text{ ft}^3,$$

Now calculate the standing idle saturation factor:

$$K_S = \frac{1}{1 + 0.053\ P\ (h_v)} \quad (3)$$
$$= 1 / [1 + 0.053(6.19)(5)]$$
$$= 0.379$$

The standing idle loss may now be calculated:

$$L_S = (2)(0.215)[(6.19)(47{,}517) / (10.731)(529.0)]\ (66)(0.379)$$
$$= 557 \text{ lb}$$

Check against the upper limit:

$$L_S \leq 5.9 D^2\ h_{le}\ W_l \quad (10)$$

where (from Table 4, for a flat bottom tank with a full liquid heel):

$$h_{le} = h_l$$

$= 1 \text{ ft}$

$\leq 5.9(110)^2(1)(5.6) = 399{,}784 \text{ lb}$

The upper limit has not been exceeded, and thus:

$L_S = \underline{557 \text{ lb}}$, standing idle emissions for days 1–2

9.3 Day 3 Sludge Removal (with Prior Stock Remaining)

As noted in section 3, sludge removal involves the following three-step daily cycle:

– Standing Idle (without forced ventilation)

– Vapor Space Purge (after a period of standing idle without forced ventilation)

– Sludge removal (with forced ventilation)

The heel of free-standing liquid was vacuumed out during the standing idle period of days 1–2, and only a partial heel remains in the sump. Forced ventilation is started up on day 3, and is run continuously into day 4, to reduce the vapor concentration in the tank.

9.3.1 Standing Idle Emissions during Day 3

The standing idle period preceding day 3 was not just an overnight cessation of sludge removal activities, but rather was the period identified as days 1–2. These emissions were accounted for in Section 9.2, so there are no additional standing idle emissions to be accounted for in day 3.

9.3.2 Vapor Space Purge Emissions during Day 3

Forced ventilation (by means of eductors, fans, or blowers) is started up on day 3. The vapors that remained in the vapor space under the floating roof are considered to have been flushed out by the first air change achieved by the forced ventilation. In that these vapors were generated by the prior full liquid heel of gasoline, the properties determined previously for the gasoline stock should be used in the estimation of these emissions. This liquid heel has now been vacuumed out (except for a partial heel remaining in the sump), and thus the height of the vapor space is now the full height under the floating roof:

$$h_v = h_d - h_l$$
$$= 6 \text{ ft} - 0 \text{ ft}$$
$$= 6 \text{ ft}$$

And then the volume of the vapor space under the floating roof has become:

$$V_V = (h_v)(\pi D^2/4)$$
$$= (6 \text{ ft})\,(\pi\,(110 \text{ ft})^2 / 4)$$
$$= 57{,}020 \text{ ft}^3$$

Given that the vapors were generated mostly from a full liquid heel, the saturation factor is taken from Table 1 as:

$$S = 0.6$$

The emissions from the initial vapor space purge are estimated from:

$$L_P = \left(\frac{PV_V}{RT}\right) M_V S \qquad (14)$$

$$= [(6.19)(57{,}020) / (10.731)(529.0)](66)(0.6)$$

$= \underline{2{,}462 \text{ lb}}$ for the initial vapor space purge of day 3.

9.3.3 Sludge Removal Emissions during Day 3

Ventilation of the tank during sludge removal was sized to achieve 5 air changes per hour under the floating roof, in accordance with API 2016.[36] The volume under the floating roof was determined above as:

$$V_V = 57{,}020 \text{ ft}^3$$

In order to achieve 5 air changes per hour, then, the required ventilation rate (Q_v) would be:

$$\begin{aligned} Q_v &= (5 \text{ hr}^{-1})(1 \text{ hr} / 60 \text{ min.})(57{,}020 \text{ ft}^3) \\ &= 4{,}752 \text{ cfm} \end{aligned}$$

An eductor mounted on the fixed roof of the tank would need about 50 feet of ductwork to draw air from under the floating roof. A manufacturer's charts shows that an 8 hp eductor, with a free-air rating of 6,250 cfm, achieves 4,850 cfm with 50 feet of ductwork. The ventilation rate (Q_v) and resulting air changes per hour (n_c) are:

$$\begin{aligned} Q_v &= 4{,}850 \text{ cfm} \\ n_c &= [4{,}850 \text{ cfm } (60 \text{ min.} / 1 \text{ hr})] / (57{,}020 \text{ ft}^3) \\ &= 5.1 \text{ air changes per hour} \end{aligned}$$

LEL monitoring on site has reported an average reading of 12% of LEL, and LEL for the calibration gas (propane) is 2.1% of air by volume. The instrument's response factor for gasoline vapors, when calibrated to propane, is unknown. The vapor concentration (C_V) is then:

$$C_V = \frac{(12\,\%\,\text{LEL})}{100} \cdot \frac{(\text{LEL of the cal gas, 2.1 volume\% in air})}{100} \cdot RF \qquad (20)$$

$$\begin{aligned} &= (12/100)(2.1/100)(1) \\ &= 0.00252 \end{aligned}$$

Check that the calculated vapor concentration does not exceed saturation:

$$C_V \le P/P_a \qquad (21)$$

$$\begin{aligned} &\le 6.19 / 14.38 \\ &\le 0.43 \end{aligned}$$

The calculated vapor concentration is less than the limit, and thus:

$$C_V = 0.00252$$

The sludge removal emissions (L_{SR}) per day, by the vapor concentration method, are:

$$L_{SR} = 60 Q_v n_{SR} t_v C_V \frac{P_a M_V}{RT} \qquad (19)$$

$$\begin{aligned} &= 60\,(4{,}850)(1)(24)(0.00252)(14.38)(66) / [10.731)(529.0)] \\ &= \underline{2{,}942 \text{ lb}} \text{ of sludge removal emissions for day 3.} \end{aligned}$$

Check that the estimated sludge removal emissions are less than the weight of liquid stock that is available to evaporate.

$$L_S \le 5.9 D^2 h_{le} W_l \qquad (10)$$

The available liquid stock includes the partial heel in the sump, as well as clingage across the bottom of the tank. The partial heel consists of 6 inches of free-standing stock liquid in a 2-foot diameter sump. The equivalent height of the liquid (h_{le}) is then calculated as shown in Table 4:

$$h_{le} = \left[(6 \text{ inches}) \left(\frac{1 \text{ foot}}{12 \text{ inches}} \right) \left(\frac{\pi \, (2 \text{ feet})^2}{4} \right) \bigg/ \left(\frac{\pi (110 \text{ ft})^2}{4} \right) \right] + \left(\frac{0.01 \text{ in.}}{12 \text{ in./ft}} \right)$$

$$= 0.0010 \text{ feet}$$

$$\text{density} = W_l$$

$$= 5.6 \text{ lbs/gallon}$$

$$L_S \leq 5.9\,(110)^2\,(0.001 \text{ ft})\,(5.6 \text{ lb/gal})$$

$$L_S \leq 400 \text{ lbs}$$

The upper limit is less than the emissions estimated from the vapor concentration, and thus:

L_{SR} = <u>400 lb</u> of sludge removal emissions for day 3.

9.4 Days 4–5 Sludge Removal (with Diluent)

All free-standing gasoline was evaporated during the forced ventilation (degassing) of day 3. During days 4–5, a 6–inch heel of kerosene is pumped in to loosen the remaining sludge in the bottom of the tank. The properties of the liquid heel during this time may be assumed to be the properties of kerosene:

B = a vapor pressure constant (from Table 3)
= 8933

h_l = the height of the stock liquid and sludge above the tank bottom at the tank shell
= 0.5 ft

M_V = the vapor molecular weight (from Table 3)
= 130 lb/lb-mole

P = the true vapor pressure of kerosene at 69.3 ^{o}F (calculated from the A and B constants given for kerosene in Table 3)
= exp[12.390 – (8933 / 529.0)]
= 0.011 psia

W_l = the stock liquid density (from Table 3)
= 7.0 lb/gal

9.4.1 Standing Idle Emissions during Days 4–5

In that the ventilation was run continuously from day 3 into day 4, there was no standing idle period immediately preceding day 4. The ventilation was shut down overnight between days 4 and 5, however, so there was an overnight standing idle period immediately preceding day 5. In that the standing idle period was limited to the nighttime, when the diurnal temperature cycle produces cooling of the vapor space, it would be expected that the direction of air flow would be of fresh air from outside the tank into the tank. Given that the direction of air flow during this time is into the tank, the nighttime periods of standing idle may be assumed to have no emissions. To the extent that vapors are generated into the vapor space during this overnight standing idle period, the associated emissions will be accounted for as the next morning's vapor space purge.

9.4.2 Vapor Space Purge Emissions during Days 4–5

As noted above, there was no standing idle period immediately preceding day 4, due to the forced ventilation having been run continuously from day 3 into day 4. There would, then, be no vapor space purge emissions to begin day 4, in that there was no prior period of standing idle and no first air change of the vapor space to flush out the vapors that would have built up during a standing idle period.

There was, however, an overnight standing idle period between days 4 and 5. There would therefore be a vapor space purge to begin the tank cleaning activities on day 5. These vapor space purge emissions are given by:

$$L_P = \left(\frac{PV_V}{RT}\right) M_V S \quad (14)$$

where:

V_V = volume of the vapor space under the floating roof

$= (h_v)(\pi D^2/4) \quad (6)$

where (from Table 4, for a full liquid heel):

$h_v = h_d - h_l$

$= 6 \text{ ft} - 0.5 \text{ ft}$

$= 5.5 \text{ ft}$

$V_V = (5.5 \text{ ft}) (\pi (110 \text{ ft})^2 / 4)$

$= 52{,}268 \text{ ft}^3$, and

$S = 0.6$ (from Table 5)

<u>Day 5 – purge of kerosene vapors</u>:

$M_V = 130$ lb/lb-mole

$P = 0.011$ psia

$L_P = [(0.011)(52{,}268) / (10.731)(529.0)](130)(0.6)$

= <u>7.9 lb</u> for the vapor space purge of day 5.

9.4.3 Sludge Removal Emissions during Days 4–5

LEL monitoring on site has reported an average reading of 3.0% of LEL, and LEL for propane is 2.1% of air by volume. A response factor is not known. The vapor concentration (C_V) is then:

$$C_V = \frac{(3\,\%\,\text{LEL})}{100} \cdot \frac{(\text{LEL of the cal gas, 2.1 volume\% in air})}{100} \cdot RF$$

$= (3.0/100)(2.1/100)(1)$

$= 0.00063$

Check that the calculated vapor concentration does not exceed saturation:

$C_V \leq P/P_a \quad (21)$

$\leq 0.011 / 14.38$

≤ 0.00076

The calculated vapor concentration is less than the limit, and thus:

$C_V = 0.00063$

The sludge removal emissions (L_{SR}) per day, by the vapor concentration method, are:

$$L_{SR} = 60 Q_v n_{SR} t_v C_V \frac{P_a M_V}{RT} \quad (19)$$

$= 60\,(4{,}850)(1)(10)(0.00063)(14.38)(130) / [(10.731)(529.0)]$

= <u>604 lb</u> per day of sludge removal emissions, for days 4 and 5.

There is no need to check that this rate of sludge removal emissions exceeds the available sludge depth, because kerosene is being pumped into the tank to maintain the 6-inch depth.

9.5 Days 6–7 Sludge Removal (No Free-standing Liquid Remaining)

The scenario for removal of the remaining volatile materials by personnel who enter the tank is similar to that for removal from outside the tank, with the exception that the 6-inch heel of sludge and kerosene has been vacuumed out. The remaining layer of kerosene-laden sludge is approximately one-half inch deep.

9.5.1 Standing Idle Emissions during Days 6–7

As for day 5, the nighttime standing idle periods may be assumed to have no emissions.

9.5.2 Vapor Space Purge Emissions during Days 6–7

The only difference in the calculation of the vapor space purge emissions from day 5 is in the assumed depth of the sludge, and therefore the height of the vapor space:

$$L_P = \left(\frac{PV_V}{RT}\right) M_V S \qquad (14)$$

where:

V_V = volume of the vapor space under the floating roof

$= (h_v)(\pi D^2/4) \qquad (6)$

where:

$h_v = h_d - h_l$

$= 6\text{ ft} - 0.5\text{ in.}\ (1\text{ ft} / 12\text{ in.})$

$= 5.96\text{ ft}$

$V_V = (5.96\text{ ft})\ (\pi\ (110\text{ ft})^2 / 4)$

$= 56{,}640\text{ ft}^3$, and

$S = 0.6$ (from Table 5)

$L_P = [(0.011)(56{,}640) / (10.731)(\ 529.0)](130)(0.6)$

= <u>8.6 lb</u> per day of vapor space purge emissions, for days 6 and 7.

9.5.3 Sludge Removal Emissions during Days 6–7

LEL monitoring on site has reported an average reading of 1.0% of LEL, and LEL for propane is 2.1% of air by volume. A response factor is not known. The vapor concentration (C_V) is then:

$$C_V = \frac{(1\%\ \text{LEL})}{100} \cdot \frac{(\text{LEL of the cal gas, 2.1 volume\% in air})}{100} \cdot RF$$

$= (1.0/100)(2.1/100)(1)$

$= 0.00021$

This is less than the upper limit of 0.00076 determined for days 4 and 5, and thus:

$C_V = 0.00021$

The sludge removal emissions (L_{SR}) per day, by the vapor concentration method, are:

$$L_{SR} = 60 Q_v n_{SR} t_v C_V \frac{P_a M_V}{RT} \qquad (19)$$

$= 60\ (4{,}850)(1)(10)(0.00021)(14.38)(130) / [(10.731)(529.0)]$

= <u>201 lb</u> per day of sludge removal emissions, for days 6 and 7.

Check that the estimated sludge removal emissions are less than the weight of the volatile fraction of the sludge that remains after the liquid heel has been vacuumed out:

$$\text{sludge weight} = 0.49\, F_e\, D^2\, d_s\, W_l \tag{22}$$

$$= 0.49\,(0.20)\,(110)^2\,(0.5)(7.0)$$

$$= 4{,}150 \text{ lb} > 402 \text{ lb (2 days of sludge removal emissions at 201 lb/day)}$$

The upper limit has not been exceeded, and thus:

L_{SR} = <u>201 lb</u> per day of sludge removal emissions, for days 6 and 7.

9.6 Refilling Emissions

The refilling volume after the sludge has been removed (V_V) is:

$$V_V = h_v\,(\pi/4)D^2 \tag{6}$$

$$= (6 \text{ ft})(\pi/4)(110 \text{ ft})^2$$

$$= 57{,}020 \text{ ft}^3$$

Refilling emissions, assuming that the tank is being refilled with RVP 10 gasoline at 60°F, are:

$$L_F = \left(\frac{PV_V}{RT}\right) M_V\, S \tag{23}$$

$$= \frac{(6.19 \text{ psia})(57{,}020 \text{ ft}^3)(^\circ\text{R lb}\cdot\text{mole})}{(10.731 \text{ psia}\cdot\text{ft}^3)(529.0^\circ\text{R})}\,\frac{66 \text{ lb}}{(\text{lb}\cdot\text{mole})}(0.15)$$

$$= \underline{615 \text{ lb}}$$

9.7 Total Emissions

The total tank cleaning emissions are:

$$L_C = L_S + L_P + L_{SR} + L_F \tag{4}$$

Emission step	Daily emissions	Emissions (lb)
Days 1-2		
standing idle	. . . .	557
Day 3		
standing idle	0	0
vapor space purge	2,462	2,462
sludge removal	400	400
Day 4		
standing idle	0	0
vapor space purge	0	0
sludge removal	604	604
Day 5		
standing idle	0	0
vapor space purge	8	8
sludge removal	604	604
Days 6-7		
standing idle	0	0
vapor space purge	8.6	17
sludge removal	201	402
Refilling	. . . .	615
Total tank cleaning emissions		5,669

10. SUMMARY

The total tank cleaning emissions (L_C) are:

$$L_C = L_S + L_P + L_{SR} + L_F \quad (4)$$

where:

L_S = standing idle emissions,

L_P = vapor space purge emissions,

L_{SR} = sludge removal emissions, and

L_F = refilling emissions.

Methods for estimating these emissions are given in this report.

Note: The emissions addressed in this report are those that leave the tank during the tank-cleaning process. This report 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 disposal), or

– emissions that may be expelled by the vacuum pump of a vacuum truck or suction pump, if such devices are used with a suction line in the tank cleaning process. If the rate of air flow and the vapor concentration are known, however, then these emissions could be estimated in a manner similar to the vapor concentration method that is used for estimating sludge removal emissions.

APPENDIX A—ALTERNATIVE METHODS OF ESTIMATING SLUDGE REMOVAL EMISSIONS

A.1 Sludge Volume Method

Sludge removal emissions can alternatively be calculated given the sludge depth and the portion of the sludge that evaporates. The average sludge depth can be measured during tank cleaning, but the portion that evaporates is more difficult to determine.

The sludge depth depends on many factors, including the stock liquid type, presence of mixers, shape of the bottom, and elevation of the outlet. Two surveys have been conducted on this issue: one by The TGB Partnership (TGB) for API in 1993 and an earlier one by Midwest Research Institute (MRI) for EPA. The results are shown in Table 8:

Table 8—Sludge Depth in Storage Tanks

Survey	refined product tanks
TGB	3”
MRI	2”

EPA’s *Alternative Control Techniques Document: VOL Storage in Floating and Fixed Roof Tanks*,[37] January 1994, section 5.2.2.1 gives an example in which 2200 pounds of emissions are created during the removal of 2,000 gal of sludge. Assuming a density of 6 lb/gal, this corresponds to about 20% of the sludge evaporating. The fraction of the sludge that evaporates in a given situation may depend on the length of time required to remove the sludge, the liquid content of it, and the volatility of that liquid.

The sludge removal emissions (L_{SR}) by the sludge volume method are:

$$L_{SR} = (\pi/4)(D \text{ ft})^2\ (d_s \text{ in.})\ F_e\ (W_l \text{ lb/gal})(\text{ft}/12 \text{ in.})(7.48 \text{ gal/ft}^3)$$

$$L_{SR} = 0.49\ F_e\ D^2\ d_s\ W_l \qquad (24)$$

where:

F_e = fraction of the sludge that evaporates,

D = tank diameter (ft),

d_s = sludge depth (in.),

W_l = stock liquid density (lb/gal), and

the constant 0.49 has units of gal/(in. ft^2).

The sludge removal emissions based on 20% evaporation are:

$$L_{SR} = 0.10\ D^2\ d_s\ W_l$$

If the tank in the example in section 9 (above) had 2 inches of sludge when it was emptied to be cleaned, and 20% of the sludge evaporated, the sludge removal emissions (L_{SR}) would be :

$$L_{SR} = 0.49\ F_e\ D^2\ d_s\ W_l$$

$$= 0.49\ (0.20)(110)^2\ (2)(5.6)$$

$$= \underline{13{,}281 \text{ lb}}$$

A.2 Air Driven Loss Method

Sludge removal emissions may also be calculated by assuming that the forced ventilation drives evaporation at the same rate as wind-driven standing idle loss from an external floating-roof tank (EFRT) with a full liquid heel. The pockets and pools of liquid in the sludge would offer less surface area than would the full liquid heel, and the liquid that is available in the sludge would tend to be heavier (less volatile) than the stock that is typically stored in the tank. On the other hand, the exhaust vents used during tank cleaning may create a higher rate of air movement than would occur under a landed external floating roof due to wind (the rate of air movement corresponding to 5 air changes per hour is very low compared to wind speeds, but wind does not act directly on the liquid surface below a landed EFRT). In that these effects are, at least to some degree, offsetting, it may be reasonable to neglect them and estimate sludge removal emissions on the same basis as for standing idle emissions from an EFRT with a full liquid heel. (A caveat is appropriate here – the equation for estimating standing idle emissions from an EFRT with a liquid heel has not been validated by field data – see the API Landing Loss Report.[38])

The air driven loss method applies the wind-driven standing idle loss equation to estimate sludge removal emissions (L_{SR}) as follows:

$$L_{SR} = 0.57\, n_{SR}\, D\, P^*\, M_V \tag{25}$$

As with the *vapor concentration method* in section 9 above, this estimate of sludge removal emissions should be compared to an upper limit equal to the total weight of sludge in the tank. Again, the sludge is conservatively assumed to consist entirely of stock liquid in establishing the emissions upper limit. The limit is expressed as:

$$L_{SR} \leq 0.49\, D^2\, d_s\, W_l$$

Using the air driven loss method to calculate the sludge removal emissions (L_{SR}) for the example in section 9 above:

$$L_{SR} = 0.57\, n_{SR}\, D\, P^*\, M_v$$

$$P^* = \frac{P / P_a}{\left(1 + \left(1 - P / P_a\right)^{1/2}\right)^2} \tag{26}$$

For a gasoline-laden sludge:

$$= (6.19/14.38) / [1 + (1 - 6.19/14.38)^{1/2}]^2$$

$$= 0.140$$

And, for five days of sludge removal:

$$L_{SR} = 0.57\,(5)(110)(0.140)(66)$$

$= \underline{2{,}896 \text{ lb}}$ total for the five days of sludge removal activities (days 3-7 in section 9).

Check that the estimated sludge removal emissions are less than the weight of available sludge weight:

$$\text{sludge weight} = 0.49 D^2\, d_s\, W_l$$

$$= 0.49\,(110)^2\,(2)(5.6)$$

$$= 66{,}405 \text{ lb} > 2{,}896 \text{ lb, } \underline{\text{okay}}.$$

If the properties of kerosene had been assumed, rather than those of gasoline, the estimated emissions become trivial:

$$L_{SR} = 0.57\, n_{SR}\, D\, P^*\, M_v$$

$$= (0.011/14.38) / [1 + (1 - 0.011/14.38)^{1/2}]^2$$

$$= 0.0002$$

$$L_{SR} = 0.57\,(5)(110)(0.0002)(130)$$

$$= \underline{8.2 \text{ lb}}$$

A.3 Comparison of Sludge Removal Emission Methods

For purposes of comparing the three methods, the ventilation rate (Q_v) may be expressed in terms of the number of air changes per hour (n_c):

$$\begin{aligned} Q_v \text{ ft}^3/\text{min} &= (n_c/\text{hr})(\pi/4)(D \text{ ft})^2(h_d \text{ ft})(\text{hr}/60 \text{ min}) \\ &= 0.0131 n_c D^2 h_d \end{aligned}$$

Substituting this equivalency for (Q_v) into equation 19:

$$L_{SR} = 1440\, Q_v\, n_{SR}\, C_V \frac{P_a M_V}{RT} \qquad (19)$$

$$= 1440\left(0.0131\, n_c\, D^2\, h_d\right) n_{SR}\, C_V \frac{P_a M_V}{10.731 T}$$

$$L_{SR} = 1.76\, n_c\, D^2\, h_d\, n_{SR}\, C_V \frac{P_a M_V}{T}$$

Table 9—Comparison of Sludge Removal Emission Estimating Methods

Method	Equation	Comments
vapor concentration	$L_{SR} = 1.76\, n_c\, D^2 h_d\, n_{SR}\, C_V \frac{P_a M_V}{T}$	This method lends itself to field measurement of the unknown parameters.
sludge volume	$L_{SR} = 0.49\, F_e\, D^2\, d_s\, W_l$	Volatility is only accounted for by estimating the fraction that evaporates.
air driven loss	$L_{SR} = 0.57\, n_{SR}\, D\, P^*\, M_V$	This method is based on the EFRT landing loss which was not field-validated.

A.3.1 Comparison of Vapor Concentration and Sludge Volume Methods

To compare the vapor concentration and sludge volume methods, equating the vapor concentration and sludge volume estimates and expressing the result in terms of the sludge depth gives:

$$1.76\, n_c\, D^2 h_d\, n_{SR}\, C_V \frac{P_a M_V}{T} = 0.49\, F_e\, D^2\, d_s\, W_l$$

$$d_s = \frac{3.59 n_c h_d n_{SR} C_v P_a M_V}{F_e W_l T} \qquad (27)$$

Using this equation, maximum sludge depths consistent with the vapor concentration method can be calculated using the maximum value for vapor concentration in the above equation. The vapor concentration (C_v) is limited by OSHA regulations 29 *CFR* 1910.106(a)(32)[39] and NFPA 69 3.3-1[40] to no more than one quarter of the LEL, for purposes of preventing an explosive atmosphere (standards for personnel safety are lower). Assuming propane as the calibration gas, the upper limit on the vapor concentration may then be expressed as:

$$\begin{aligned} C_v &= 0.25(0.021) \\ &= 0.0053 \end{aligned}$$

Using this maximum vapor concentration, the vapor concentration method may be compared to the sludge volume method using equation 27. For a sample case, using typical values for gasoline (see Table 3) of:

M_v = 66 lb/lb-mole,

W_l = 5.6 lb/gal,

and values for the other parameters of:

n_c = 5.1 air changes per hour,

h_d = 6 ft,

P_a = 14.38 psia,

T = 69.3°F,

and the assumed 20% of the sludge volume evaporating:

F_e = 0.20

Applying these values to equation 27 gives:

$$d_s = \frac{3.59(5.1)(6)(n_{SR})(0.0053)(14.38)(66)}{(0.20)(5.6)(459.7 + 69.3)}$$

d_s = 0.93 n_{SR}, or about 1 inch per day.

This calculated maximum rate of about 1 inch of sludge removal per day is based on maintaining the vapor concentration at about 25% LEL. More probable vapor concentrations are usually much less than the 25% LEL specified for explosion prevention; in fact, API 2016[41] requires the vapor concentration to be below 10% LEL during sludge removal activities. Vapor concentration levels and corresponding amounts of sludge removed, assuming that 20 percent of the sludge evaporates, are shown in Table 10 (assuming the parameter values listed above).

Table 10—Comparison of Vapor Concentration and Sludge Volume Methods

Vapor Concentration Level (% LEL)	Depth of Sludge Removed (with 20% evaporated)	
	per day	total for 5 days
25	1 in.	5 in.
10	3/8 in.	2 in.
1	0.04 in.	0.2 in.

In order to remove 2 inches of sludge in 5 days, as given in the example, the vapor concentration would have to average 10% LEL. Given that observed vapor concentration levels tend to be well under 10% LEL, the assumption in the sludge volume method that 20% of the sludge evaporates may be unrealistically high.

Other limitations to the sludge volume method include its failure to account for the period of time that it takes to clean the tank, and its failure to account for any mitigation of emissions that may result from the type of sludge removal employed. In the example, for instance, the sludge was flooded with kerosene, which is far less volatile than the gasoline that was initially stored in the tank.

A.3.2 Comparison of Vapor Concentration and Air Driven Loss Methods

The vapor concentration and air driven loss methods can be compared by equating the vapor concentration and air driven loss estimates:

$$1440\, Q_v\, n_{SR}\, C_V \frac{P_a M_V}{RT} = 0.57\, n_{SR}\, D\, P^*\, M_V$$

$$C_v Q_v = 0.00040 \frac{D\, P^*\, R\, T}{P_a} \qquad (28)$$

As with the example given in section 9, use the values for kerosene in determining the vapor pressure function (P^*):

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

$$= \frac{0.011/14.38}{\left(1+\left[1-\left(0.011/14.38\right)\right]^{0.5}\right)^{2}}$$

$= 0.00019$

The vapor concentration predicted from the air driven loss method, then, is

C_v = (0.00040)(110)(0.00019)(10.731)(529) / [(14.38)(4,850)] = 0.00000068 = 0.000068%

Assume propane as the calibration gas, which has an LEL of about 2.1%.[42] The %LEL is then:

% LEL = 100 (0.000068 / 2.1)

= 0.0036% LEL

For this example, the air driven loss method predicts a very low vapor concentration, which may not be realistic.

A.4 Comparison Summary

For the example given in section 9 above, the sludge removal emissions for each of the three estimating methods are:

Table 11—Comparison of Example Results by Sludge Removal Estimating Method

Method	Assumed Sludge Properties	Assuming	Assumed No. Days	Total Sludge Removal Emissions* (lb)
Vapor Concentration Method	as kerosene	LEL as measured	5	5,113
Sludge Volume Method	as gasoline	20% evaporated		13,281
Air Driven Loss Method	as gasoline		5	2,896
Air Driven Loss Method	as kerosene		5	8

*Estimates of all emissions associated with the five days during which forced ventilation was in operation.

In conclusion, for the three alternatives offered for estimating *sludge removal* emissions:

The Air Driven Loss Method is based on air (wind) driven loss past a floating roof rim seal, and thus would not be expected to be applicable to a fixed-roof tank. Furthermore, the equation for estimating standing idle emissions from an EFRT with a liquid heel has not been validated by field data, even for applicability to floating-roof tanks.

The Sludge Volume Method would be accurate if the proper value could be determined for the fraction of sludge that is lost to evaporation. A value of 20 percent has been suggested, but there is no basis for selecting this value, and no way to readily confirm the value in the field. Furthermore, it is not likely that the same value would apply to all sludges, and there is no accommodation in the equation for variation in the vapor pressure of the previously stored stock (or of any cutter stock used in the tank cleaning process).

The Vapor Concentration Method is the only method that lends itself to field measurement of the key unknown involved in the calculation. It accounts for the volatility of the stock and for the period of time required to clean the tank. Of the methods considered, it is the preferred choice.

APPENDIX B—LEL MONITORS AND RESPONSE FACTORS

B.1 LEL Monitors

An LEL monitor is a type of combustible gas monitor that displays the measurement in terms of %LEL. LEL is an acronym for the *lower explosive limit*, also called the *lower flammable limit*. The lower explosive limit is defined by NFPA as follows:

> In the case of gases or vapors that form flammable mixtures with air, oxygen, or other oxidizers . . there is a minimum concentration of the material below which propagation of flame does not occur. . . In popular terms, a mixture below the lower explosive limit is too "lean" to burn.[43]

The LEL is usually expressed as a percent by volume of the combustible gas in air. LEL values for various volatile materials are given in NFPA Publication 325.[44] The display of an LEL monitor, being expressed as %LEL, is therefore a percent of a percent. In order to convert the display of an LEL monitor to a volume concentration, the measurement (%LEL) is multiplied by the LEL of the gas to which the monitor has been calibrated.

For example, an LEL monitor may be used to measure methane vapors. The LEL of methane is 5% by volume. If the LEL monitor has been calibrated to methane, and displays 20%LEL when measuring methane vapors, then the concentration of the methane gas in air is 20% of 5%, or 1% by volume.

B.2 Response Factors

In the example given above, the LEL monitor is calibrated to methane, and is used to measure methane vapors. In most applications, however, the vapors being measured are not of a pure compound, but rather consist of a mixture of compounds. Gasoline, for example, generally consists of about 200 compounds. In common practice, LEL monitors are not calibrated to the actual mixture of gases that may be present, but rather are calibrated to a specified gas standard, such as methane or propane.

Regardless of the type of technology used for the sensor in an LEL monitor or other type of combustible gas monitor, the sensor will respond differently to different gases. The difference in response is partly a function of the number of carbon items in the molecules that are present, and how those carbon atoms are bound in the molecular structure. The response of the sensor to different gases can also be affected by design issues pertaining to the geometry and arrangement of the individual instrument. The sensor response may be further affected by the presence of certain non-combustible compounds, such as water vapor.

The general relationship of the actual concentration of organic vapors in air to the value displayed by a combustible gas monitor may be expressed as follows:

$$AC = DV \times RF$$

Where:

AC is the actual concentration of the organic vapors in air,

DV is the display value (the value displayed by the combustible gas monitor), and

RF is the response factor (a correction factor).

It is evident that this expression assumes that the relationship between the display value and the actual value is a linear function. In reality, this is not always the case. When an instrument is tested for linearity, the test involves measuring the relationship of display values to known concentrations of the gas to be measured in order to determine whether the display is a linear function of the actual concentration.

The difference in sensor response to the actual vapors present, versus the gas to which the sensor was calibrated, is further complicated for an LEL monitor by virtue of the LEL itself being different for different gases. The display of an LEL monitor is not a direct measure of concentration, but rather is expressed in terms of the LEL of the calibration gas. The LEL of the calibration gas, however, may be quite different from the LEL of the actual vapors being measured. For example, an LEL monitor may be calibrated to methane, which has an LEL of 5%, and then used to measure gasoline vapors, which have an LEL of about 1.4%.[45]

Given the numerous variables that may affect the response of a combustible gas sensor to a given vapor concentration, relative to the response of the sensor to a given calibration gas, the development of response factors is most accurately accomplished by performing tests with the individual instrument to be used and the vapors to be measured. This type of testing is very often infeasible, however, and the user is inclined to seek some "rule of thumb" for approximating a response factor. Unfortunately, such a "rule of thumb" is rarely applicable, as illustrated by the table below. This table shows response factors for common hydrocarbon compounds, as given in EPA's *Protocol for Equipment Leak Emission Estimates*.[46]

Table 12—Response Factors of Individual Instruments for Selected Target Compounds

		Actual Concentration, Instrument Identification, and Response Factors					
		at 10,000 ppmv		at 500 ppmv			
Target Compound	MW	Foxboro OVA-108	Bacharach TLV	Foxboro OVA-108	Foxboro OVA-128	Foxboro OVA-128	Heath DP III
methane	16.04	1.00	1.00				
ethane	30.07	0.57	0.73				
propane	44.10	0.88	0.63				
butane	58.12	0.38	0.68				
isobutane	58.12	0.30	0.61				
pentane	72.15	0.42	0.62				
benzene	78.11	0.21	1.07	0.56	0.54	0.5	0.38
cyclohexane	84.16	0.36	0.72				
hexane	86.18	0.31	0.72	1.42	1.49	1.33	0.93
toluene	92.13	0.33	2.32	0.87	0.87	0.76	0.57
heptane	100.20	0.30	0.75				
ethylbenzene	106.17	0.70	3.14	0.77	0.76	0.66	0.51
xylene, m-	106.17	0.30	3.56	0.89	0.89	0.75	0.54
octane	114.23	1.04	2.06				
average response factors:		**0.51**	**1.33**	**0.90**	**0.91**	**0.80**	**0.59**

In this table, the instruments were all calibrated to methane, and then used to measure leaks of the target compound at either 10,000 ppmv or 500 ppmv, as indicated. It is apparent that the response factor varies with different manufacturers (*e.g.*, Foxboro versus Bacharach), and that it even varies with the same model of instrument from the same manufacturer (comparing the two Foxboro OVA-128 detectors used at 500 ppmv). Furthermore, comparing the response factors for the Foxboro OVA-108 at 10,000 ppmv to the response factors for this same instrument at 500 ppmv, it is apparent that the response of this instrument is not linear.

Given this absence of a discernible pattern, manufacturers typically recommend using a response factor of 1 when the actual response factor is not known.

APPENDIX C—DATA COLLECTION FORMS

The forms presented in this appendix may be used for collecting the data needed for estimating emissions from tank cleaning events. There are five forms, corresponding to the following five phases of tank cleaning.

1) Standing Idle. This is for the initial standing idle period, between emptying the tank (normal pumpout) and the commencement of forced ventilation (by means of eductors, fans, or blowers). This form should be filled out even if forced ventilation begins immediately upon the completion of normal pumpout, in that this form contains some of the basic information about the tank and its location.

Company ______________________ Location _______________________ Tank ID No. _________ Diameter _________ft Tank Height _______ft Paint Color ____________ Paint Condition (Good or Poor) _______ Fixed Roof Type (cone, dome, or open top): ______________ If cone-down bottom: bottom slope ____in./ft Description of tank stock prior to cleaning: ______________________________	DATA COLLECTION FORM 1 of 5 **STANDING IDLE PHASE** Date the tank was emptied (normal pumpout down to heel): __ __ / __ __ / __ __ __ __ Type of heel (full, partial or drain dry): _____________________________ If full heel, liquid height at shell ______ft If partial heel: heel diameter (sump) ______ft liquid height (in sump) _____ft Floating Roof (Y/N) ____ Floating roof leg height _____ft

2) Sludge Removal (with prior stock remaining). This form is needed if there is a period of forced ventilation during which a heel (either full or partial) of the prior stock remains in the tank. If the tank cleaning does not involve such a phase, then this form is not needed.

Start date – forced ventilation begins: __ __ / __ __ / __ __ __ __ Ventilation rate _________cfm Hours/day of venting _____hr Average % LEL (of tank headspace or vented stream) ________ % LEL Is ventilation routed to vapor control? (Y/N) ____ Completion date – this phase: __ __ / __ __ / __ __ __ __	DATA COLLECTION FORM 2 of 5 **SLUDGE REMOVAL PHASE** (with heel of prior stock) Calibration gas _________________ LEL of calibration gas _______% Response Factor (if known) _______ If heel condition changed since Standing Idle phase, type of heel (full, partial or drain dry): __________________ If full heel, liquid height at shell _____ft If partial heel: heel diameter (sump) _____ft liquid height (in sump) _____ft

3) Sludge Removal (with low volatility diluent). This form is needed if there is a period of forced ventilation during which a heel of diluent (cutter stock) is maintained in the tank. If the tank cleaning does not involve such a phase, then this form is not needed.

Start date – flooded with diluent: __ __ / __ __ / __ __ __ __ Ventilation rate _________cfm Hours/day of venting _____hr Average % LEL (of tank headspace or vented stream) ________ % LEL Is ventilation routed to vapor control? (Y/N) ____ Completion date – this phase: __ __ / __ __ / __ __ __ __	DATA COLLECTION FORM 3 of 5 **SLUDGE REMOVAL PHASE** (with heel of diluent) Calibration gas _________________ LEL of calibration gas _______% Response Factor (if known) _______ A full liquid heel is assumed while the tank bottom is flooded with diluent. Description of diluent (cutter stock): _____________________________________ Height of liquid heel at shell _____ft

4) Sludge Removal (with no free-standing liquid remaining). This form is needed for the final phase of tank cleaning, during which there is no free-standing liquid (either of the prior stock or of diluent) and only sludge remains in the bottom of the tank.

Start date – only sludge remains (no free-standing liquid): __ __ / __ __ / __ __ __ __ Avg depth of sludge ____inches Ventilation rate _________cfm Hours/day of venting _____hr Is ventilation routed to vapor control? (Y/N) ____ Completion date – this phase: __ __ / __ __ / __ __ __ __	DATA COLLECTION FORM 4 of 5 **SLUDGE REMOVAL PHASE** (with sludge only) Calibration gas _________________ LEL of calibration gas _______% Response Factor (if known) _______ Average % LEL (of tank headspace or vented stream) ________ % LEL

5) Refilling. This form is needed for refilling the tank at some future time, after it has been cleaned.

Start date – tank refilling: __ __ / __ __ / __ __ __ __ Description of stock for refilling: ______________________________ Are displaced vapors routed to vapor control? (Y/N) ____	DATA COLLECTION FORM 5 of 5 **REFILLING PHASE** Completion date – this phase: __ __ / __ __ / __ __ __ __ Hours to refloat the roof (for floating-roof tanks only): _____hr

The following examples are merely examples 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.

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