

Evaporative Loss from the Cleaning of Storage Tanks

TECHNICAL REPORT 2568
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Measurement Coordination

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Evaporative Loss from the Cleaning of Storage Tanks

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.

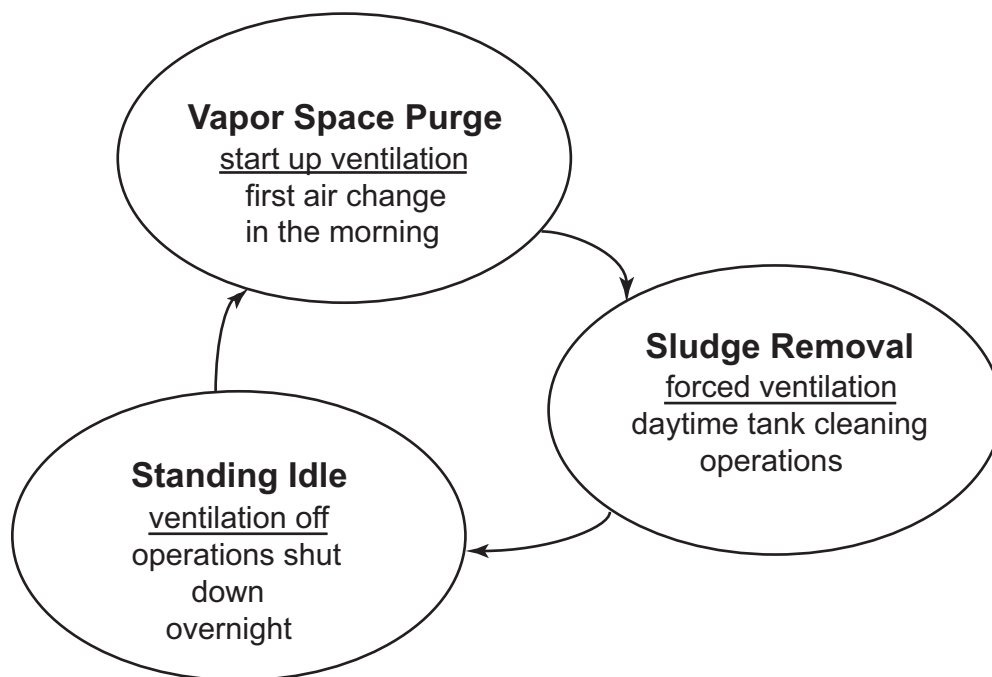


Figure 1—Daily Tank Cleaning Cycle

- 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 Report² 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			
<u>Fixed Roof Tanks</u>	<u>Internal Floating Roof Tanks with a Liquid Heel</u>	<u>External Floating Roof Tanks with a Liquid Heel</u>	<u>Drain-Dry Floating-Roof Tanks</u>
<u>Initial standing idle period upon emptying the tank (Section 4):</u>			
Included with normal standing storage (breathing) losses (see API 19.1 ³) Thus $L_S = 0$	{equations 9 & 10} $L_S = n_d K_E \left(\frac{P V_V}{RT} \right) M_V K_S$ $\leq 5.9 D^2 h_{le} W_l$	{equations 11 & 10} $L_S = 0.57 n_d D P^* M_V$ $\leq 5.9 D^2 h_{le} W_l$	{equations 12 & 13} $L_S = 0.0063 W_l (\pi/4) D^2$ $\leq P V_V M_V S / (RT)$ where: $S = 0.6$
<u>Subsequent (overnight) standing idle periods during the daily cleaning cycle (Section 6):</u>			
$L_S = 0$	$L_S = 0$	$L_S = 0$	$L_S = 0$
Vapor Space Purge Emissions			
{equation 14} $L_P = \left(\frac{P V_V}{RT} \right) M_V S$, where V_V and S are evaluated as shown below:			
<u>Fixed-Roof Tanks</u> {equation 7} $V_V = H_{VO} (\pi D^2/4)$	<u>Floating-Roof Tanks</u> {equation 6} $V_V = (h_v)(\pi D^2/4)$		
	<u>Full Liquid Heel</u>	<u>Partial Liquid Heel</u>	<u>Drain-Dry Tanks</u>
<u>Initial vapor space purge upon commencing forced ventilation (Section 5):</u>			
{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 $C_{sf} S =$ $0.6 \left(1 - \frac{\frac{0.57 D P^* RT}{P V_V} - K_E K_S}{K_E K_S + 0.6} \right)$	{equation 18; Table 6} IFRT $S = 0.5$ EFRT S is taken as $C_{sf} S =$ $0.5 \left(1 - \frac{\frac{0.57 D P^* RT}{P V_V} - K_E K_S}{K_E K_S + 0.5} \right)$	{Table 6} $S = 0$
<u>Subsequent vapor space purge emissions during the daily cleaning cycle, after standing idle overnight (Section 6):</u>			
$S = 0.25$	$S = 0.6$	$S = 0.5$	$S = 0.5$
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: $L_{SR} \leq 5.9 D^2 h_{le} W_l$	{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} $L_F = \left(\frac{P V_V}{RT} \right) M_V S$, where $S = 0.15$ and V_V is evaluated as shown below:			
<u>Fixed-Roof Tanks</u> included with normal working losses (see API 19.1) Thus $L_F = 0$	<u>Floating-Roof Tanks</u> {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 2015⁴ 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

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); = $\frac{\Delta T_V}{T} \left(1 + \frac{0.50 B P}{T (P_a - P)} \right)$ see API 19.1 ⁷ for alternative equations for K_E [floating-roof tanks]	(2)
K_S	is the standing idle saturation factor (dimensionless); = $\frac{1}{1 + 0.053 P (h_v)} \leq S$	(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);	$= \left(\frac{P / P_a}{1 + [1 - (P / P_a)]^{0.5}} \right)^2 \quad (5)$
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 °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;	= $0.72(T_{MAX} - T_{MIN}) + 0.028aI$, or = 20°F (= 20°R) if unknown
T	is the average temperature of the vapor space	in degrees Rankine;	= avg ambient temp (°F) + 459.7
V_V	is the volume of the vapor space.....	in feet ³ ;	= $(h_v)\pi D^2/4$ [floating-roof tanks] (6) = $(H_{VO})\pi D^2/4$ [fixed-roof tanks] (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

Petroleum Stock	W_l	M_v	A	B	True Vapor Press, P (psia), at Selected Temp's (°F)					
	<u>lb/gal</u>	<u>lb/lb-mole</u>	<u>dim'less</u>	<u>°R</u>	<u>40</u>	<u>50</u>	<u>60</u>	<u>70</u>	<u>80</u>	<u>90</u>
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.

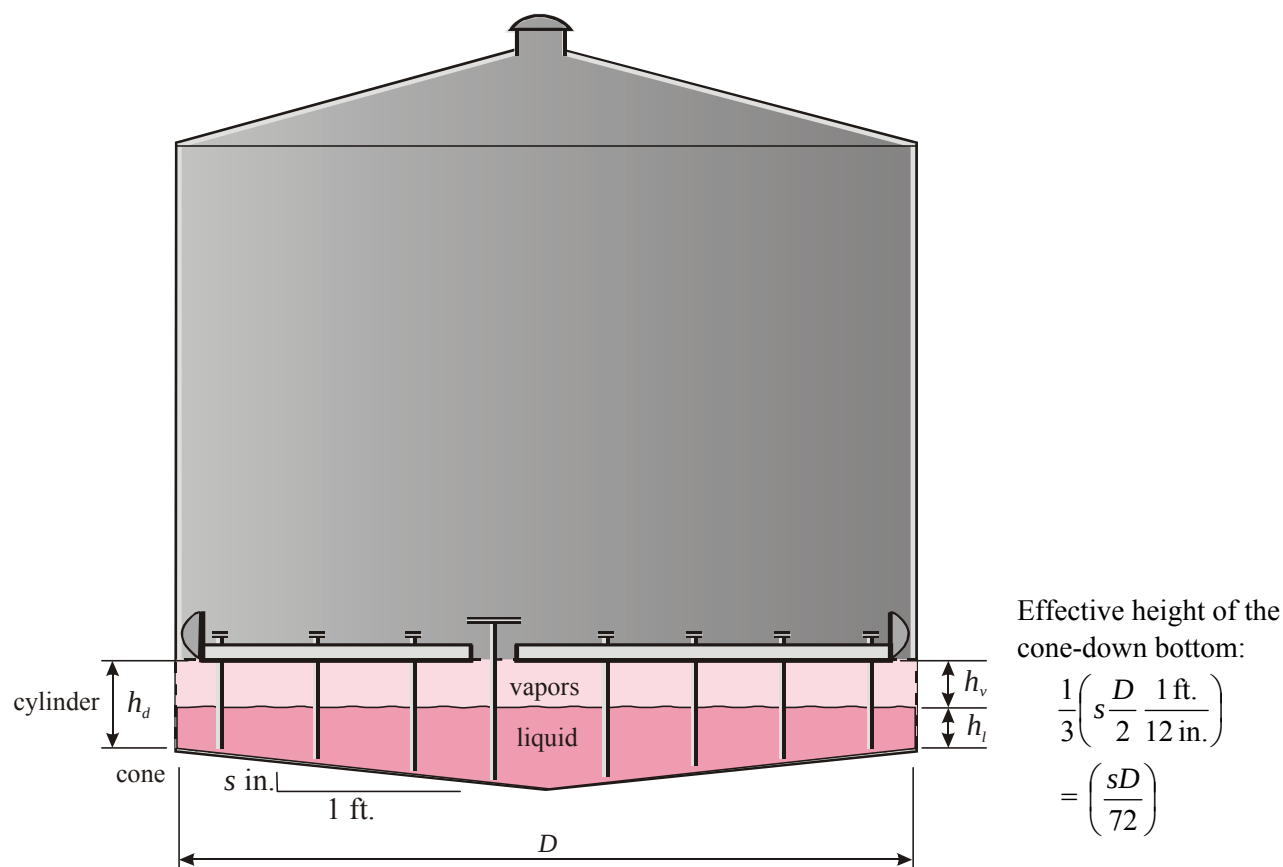


Figure 2—Height of the Vapor Space under a Landed Floating Roof

Table 4—Height of the Vapor Space under a Floating Roof

Scenario	Condition	Expression for height of the vapor space (h_v)
<u>General Expression</u>	<u>Slope convention:</u> 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)
<u>Full liquid heel</u>	$h_{le} = \left(h_l + \frac{sD}{72} \right)$	$h_v = h_d - h_l$
<u>Partial liquid heel</u> (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 <u>volatile material remaining</u> (drain dry tanks or any tank after sludge removal)	$h_{le} = 0$	$h_v = \left(h_d + \frac{sD}{72} \right)$
<u>Flat bottom</u> (including slight cone-up bottoms)	$s = 0$ h_{le} is evaluated per the applicable case above.	$h_v = h_d - h_{le} \{ = h_d - h_l, \text{ given } s = 0 \}$

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) <u>Removal Using Fixed Connections</u>. a) <u>Normal Pumpout</u>. As much stock liquid as possible is pumped out through the tank outlet in the normal manner (<i>i.e.</i>, until the liquid level has dropped below the open end of the outlet line, and no more liquid moves through the outlet). b) <u>Standing Idle</u>. 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 <i>completely emptying</i> or <i>stripping</i>, with <i>cleaning</i> 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 <i>standing idle</i> 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 <i>sludge removal</i>, 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 <i>sludge removal</i> 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 <i>standing idle</i> 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 <i>purge the vapor space</i> 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.