

Manual of Petroleum Measurement Standards Chapter 19.6

Part 1—Evaporative Loss from Storage Tank Floating-roof Landings

FIRST EDITION, FEBRUARY 2017



AMERICAN PETROLEUM INSTITUTE

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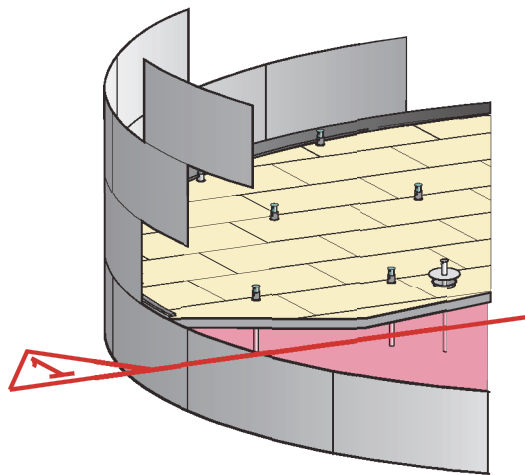
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Introduction

The purpose of this study was to investigate storage tank emissions that may result from landing and subsequently refloating a floating roof. The existing emission factors for floating-roof tanks [2],[22] are based on the assumption that the floating roof is continuously floating on the stored stock liquid. Additional emissions may occur, however, if the tank is emptied such that the floating roof is no longer floating.

When the liquid level approaches the bottom of the tank, the floating roof lands on deck legs or other supports that prevent it from dropping any further as the stock liquid continues to be removed. Further withdrawal of stock liquid could then potentially form a partial vacuum beneath the landed floating roof. If the receding liquid were to create an excessive partial vacuum, the floating roof could collapse. To avoid this condition, a vacuum-breaker vent on the floating roof opens automatically as the floating roof lands (see Figure 1). The vapor space created under the floating roof is thereby freely vented to the space above the floating roof. Even in the case of a self-closing vacuum-breaker, the vapor space beneath the floating roof is vented via the other deck fittings and the rim seal, which is effectively rendered vapor mounted once the liquid level drops below the bottom of the rim seal.

Vapor loss (and the corresponding emissions to the atmosphere) may occur while the tank remains nominally empty and the floating roof continues to stand idle in this landed condition (see Figure 2). Additional emissions may occur during the refilling of the tank, as the vapor space beneath the floating roof is displaced by the incoming stock liquid (see Figure 3). This study sought to quantify these floating-roof landing loss emissions.



Evaporative Loss from Storage Tank Floating-roof Landings

1 Scope

The emissions characterized as floating-roof landing losses in this study are those that would be expected to occur if a floating roof is landed in the course of normal operations and subsequently refilled. This study does not address emissions that may result from additional activities, such as degassing or tank cleaning, that may occur while the tank is empty.

The model is intended for use with any petroleum liquid. The inclusion in the model of the stock liquid's physical properties (i.e. true vapor pressure, vapor molecular weight, and liquid density) appears to effectively differentiate crude oil from gasoline, and therefore no further differentiation was made in the form of product factors or other product-specific adjustments.

The model does not directly address standing idle losses for partial days, but it would be reasonable to estimate the emissions for a partial day by estimating the standing idle emissions for a single day and then prorating that estimate by the number of hours that the floating roof was actually landed.

Any emission factor is properly understood as representative of the actual emission rates that are typical for a population of emission points. For a non-uniform population, however, there is an inherent level of uncertainty associated with the application of the general emission factor to any individual emission point. Some of the critical sources of uncertainty in this model of floating-roof landing losses are addressed in the comments on the confidence associated with each step of the model. As noted in these comments, some of the variables have not been well defined, and the values shown are intended to serve only as placeholders—pending further research.

2 Normative References

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

[API MPMS Chapter 19.1](#), *Evaporative Loss from Fixed-roof Tanks*

[API MPMS Chapter 19.2](#), *Evaporative Loss from Floating-roof Tanks*

[API MPMS Chapter 19.4](#), *Evaporative Loss Reference Information and Speciation Methodology*

[API MPMS Chapter 19.5](#)/EI Hydrocarbon Management HM 65 ¹, *Atmospheric Hydrocarbon Emissions from Marine Vessel Transfer Operations*

[API Technical Report 2568](#), *Evaporative Loss from the Cleaning of Storage Tanks*

3 Variables and Symbols

Symbol	Description	Units	Source
B	constant from Antoine's equation	°R	from Table 2 (for historical purposes only)
C_{sf}	filling saturation correction factor	dimensionless	$= 1 - \frac{[\text{Equation (19)} - \text{Equation (5)}]}{[\text{Equation (5)} + \text{Equation (25)}]} \quad (29)$

¹ Energy Institute, 61 New Cavendish Street, London W1G 7AR, UK, www.energyinst.org.

Symbol	Description	Units	Source
$C_{sf} = 1 - \frac{\left((0.57 \cdot 1 \cdot D \cdot P^* \cdot M_v) - \left(1 \cdot K_E \cdot \left(\frac{P_{VA} \cdot V_v}{R \cdot T_v} \right) \cdot M_v \cdot K_S \right) \right)}{\left(1 \cdot K_E \cdot \left(\frac{P_{VA} \cdot V_v}{R \cdot T_v} \right) \cdot M_v \cdot K_S \right) + \left(\left(\frac{P_{VA} \cdot V_v}{R \cdot T_v} \right) \cdot M_v \cdot (1 \cdot S) \right)}$			
D	tank diameter	ft	as specified by the user
h_{le}	effective height of the stock liquid	ft	as specified by the user ^a
h_v	height of the vapor space under the floating roof	ft	as specified by the user ^a
I	daily total insolation on a horizontal surface	Btu/(ft ² day)	as specified by the user
K_E	vapor space expansion factor	dimensionless	$= \frac{\Delta T_v}{T_{LA}} + \frac{\Delta P}{P_a - P_{VA}} \quad (6a)$
K_S	standing idle saturation factor	dimensionless	$= \frac{1}{1 + 0.053 (P_{VA} h_v)} \leq S \quad (13)$
L_F	filling loss per episode	lb	as calculated per Table 1
L_S	standing idle loss per episode	lb	as calculated per Table 1
M_v	stock vapor molecular weight	lb/lb-mole	as specified by the user, or Table 2
n_d	number of days the tank stands idle with the floating roof landed	dimensionless	as specified by the user
P^*	vapor pressure function	dimensionless	$= \frac{P_{VA} / P_a}{\left(1 + \left[1 - (P_{VA} / P_a) \right]^{0.5} \right)^2} \quad (17)$
P_a	atmospheric pressure at the tank location	psia	as specified by the user
P_{VA}	true vapor pressure of the stock liquid at the average daily liquid surface temperature	psia	as specified by the user, or Table 2
P_{VN}	true vapor pressure of the stock liquid at the average daily minimum liquid surface temperature	psia	as specified by the user, or Table 2
P_{VX}	true vapor pressure of the stock liquid at the average daily maximum liquid surface temperature	psia	as specified by the user, or Table 2
R	ideal gas constant	psia ft ³ /(lb-mole °R)	= 10.731
S	filling saturation factor	dimensionless	as stipulated in Table 1
T_B	average temperature of the bulk liquid below the floating roof	°R	= average ambient temperature (°F) + 459.67

Symbol	Description	Units	Source
T_{LA}	average temperature of the liquid surface below the floating roof	$^{\circ}\text{R}$	$= T_B$
T_{LN}	average daily minimum temperature of the liquid surface below the floating roof	$^{\circ}\text{R}$	$= T_{LA} - 0.25\Delta T_V$
T_{LX}	average daily maximum temperature of the liquid surface below the floating roof	$^{\circ}\text{R}$	$= T_{LA} + 0.25\Delta T_V$
T_{MAX}	average daily maximum ambient temperature	$^{\circ}\text{F}$	as specified by the user
T_{MIN}	average daily minimum ambient temperature	$^{\circ}\text{F}$	as specified by the user
T_V	average temperature of the vapor below the floating roof	$^{\circ}\text{R}$	$= T_B$
V_V	volume of the vapor space	ft^3	$= h_v \pi D^2 / 4$
W_1	stock liquid density	lb/gal	as specified by the user, or Table 2
y	average concentration by volume of vapors in the vapor space air	dimensionless	$= (P_{VA}/P_a)S$ (3)
α	tank surface solar absorptance	dimensionless	as specified by the user
ΔP_V	daily stock vapor pressure range	psia	$= P_{VX} - P_{VN}$
ΔT_V	average daily vapor temperature range	$^{\circ}\text{R}$	as calculated from Equation (7), or 20°F ($= 20^{\circ}\text{R}$) if unknown
^a See Section 7 for adjustment to h_v and h_{le} in the case of a cone-bottom tank.			

4 Proposed Estimating Methods

4.1 General

Floating-roof tanks were segregated into the following categories for purposes of estimating landing losses:

- internal floating-roof tanks (IFRTs) with a full or partial liquid heel,
- external floating-roof tanks (EFRTs) with a full or partial liquid heel, and
- IFRTs and EFRTs that drain dry (drain-dry tanks).

The two modes of vapor loss (standing idle and filling) are evaluated differently for each of these categories of floating-roof tanks. These modes are discussed briefly below and in more detail in Section 6.

4.2 Standing Idle Loss

The first two categories are described as having a liquid heel, which is a reference to stock liquid remaining in the bottom of the tank as it stands idle after having been emptied (see Figure 4). This heel of stock liquid provides a continuing source of vapors to replace those expelled by breathing (in the case of an IFRT) or wind action (in the case of an EFRT). For each of these cases, then, standing idle loss is a process that is repeated on a daily basis.

The third category is described as drain dry, which refers to a tank that is designed to drain its entire bottom to a sump (see Figure 5). The tank's withdrawal line is located in the sump in a manner that leaves virtually no free-standing liquid in the tank after it has been emptied. The only stock liquid available for evaporation, then, is that which clings to the tank bottom and other wetted surfaces under the floating roof. Once this thin film has evaporated, there is no free stock liquid remaining to replenish vapors under the floating roof. Standing idle loss from a drain-dry tank does not continue to occur day after day, but rather is limited to a one-time evaporation of the liquid clinging to the wetted surfaces.

A tank only qualifies as a drain-dry tank if all of the free-standing liquid has been removed. If the tank drains to a sump, but a heel of free-standing liquid is left in the sump, then the tank would be considered to have a partial liquid heel. Flat bottom tanks that have most of the free-standing liquid removed by means of a vacuum truck typically have pools of liquid remaining and should generally be considered to have a partial heel as well.

4.3 Filling Loss

Each of these categories experiences filling loss in addition to the standing idle loss. The filling loss is assumed to include vapors from two sources. The first source is those vapors that remain under the floating roof at the end of the standing idle period. These are the vapors residing in the vapor space immediately prior to the introduction of incoming stock liquid and are referred to as the arrival component of vapors. Additional vapors are generated by the incoming liquid itself. This source is referred to as the generated component of vapors. Each of these vapor components may be represented by a saturation factor applied to the vapor space volume.

4.4 Total Landing Loss

The total loss for a given floating-roof landing episode is the sum of the standing idle loss and the filling loss, as shown in Equation (1).

$$L_T = L_S + L_F \quad (1)$$

where

L_T is the total landing loss per episode (pounds);

L_S is the standing idle loss per episode (pounds);

L_F is the filling loss per episode (pounds).

4.5 Landing Loss Estimation Equations

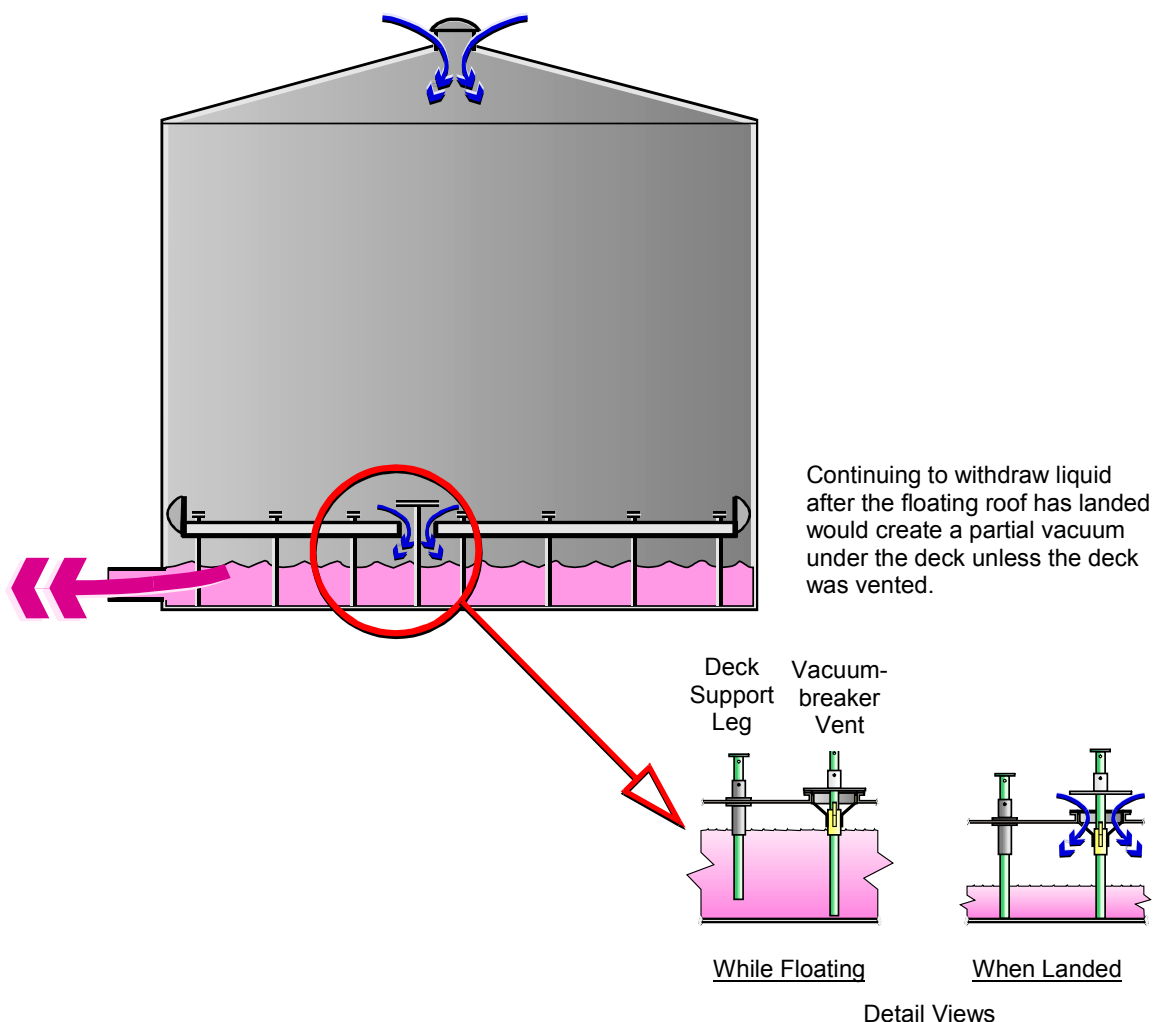
Proposed methods for estimating standing idle and filling losses for each of the three categories of tank design are summarized in Table 1. The expressions shown are for estimating the emissions for a single episode of landing the floating roof. An estimate of annual floating-roof landing losses may be obtained by summing the estimated emissions of all the landing episodes that occur during a given year.

Table 1—Summary of Floating-roof Landing Loss Estimation Methods by Tank Type (per Episode)

	Internal Floating-roof Tanks with a Liquid Heel (daily)	External Floating-roof Tanks with a Liquid Heel (daily)	All Drain-dry Tanks (one-time event)
Standing Idle Loss			
Equation	Equations (5) and (15)	Equations (19) and (15)	Equation (23)
	$L_S = n_d K_E \left(\frac{P_{VA} V_v}{RT_v} \right) M_v K_S$ but $\leq 5.9 D^2 h_{lc} W_1$	$L_S = 0.57 n_d DP^* M_v$ but $\leq 5.9 D^2 h_{lc} W_1$ see Note 1	$L_S = 0.0063 W_1 (\pi D^2 / 4)$ but $\leq (P_{VA} V_v / RT_v) M_v S$ where $S = 0.60$
Standing idle saturation factor, K_S	K_S from Equation (13); not to exceed S for filling	not applicable	not applicable
Filling Loss			
Equation	Equation (25)	Equation (25)	Equation (25)
	$L_F = \left(\frac{P_{VA} V_v}{RT_v} \right) M_v (C_{sf} S)$ where $C_{sf} = 1.0$ see Notes 2 and 3	$L_F = \left(\frac{P_{VA} V_v}{RT_v} \right) M_v (C_{sf} S)$ but $C_{sf} S \geq 0.15$ see Note 2	$L_F = \left(\frac{P_{VA} V_v}{RT_v} \right) M_v (C_{sf} S)$ where $C_{sf} = 1.0$ see Note 3
Filling saturation factor, S	$S = 0.60$ for a full heel $S = 0.50$ for a partial heel	using the IFRT value for S and C_{sf} is from Equation (29)	$S = 0.15$
NOTE 1 Equation (19), for the standing idle loss of an EFRT, should be regarded as a placeholder. While there are sufficient field and lab data available to demonstrate that wind is a factor in this case, there are not sufficient data to support a particular formulation of the model. In the absence of data, a placeholder was selected that is a relatively simple function of tank diameter, yet yields results that fall within reasonable upper and lower bounds. The other cases lend themselves to derivable theoretical equations, but there are varying degrees of uncertainty in the values assigned to the variables. These uncertainties are discussed in the text of the report. NOTE 2 The filling loss for tanks with a liquid heel is limited by the following upper bound: $L_F \leq (5.9 D^2 h_{lc} W_1 - L_S) + 0.15 \left(\frac{P_{VA} V_v}{RT_v} \right) M_v \quad (26)$ NOTE 3 The filling saturation correction factor for wind, C_{sf}, has been included in the filling loss equations for both IFRTs and drain-dry tanks, to allow using the same equation for all scenarios. However, C_{sf} can be neglected or set equal to 1.0 for IFRTs in that the landed floating roof in an internal floating-roof tank or a covered floating-roof tank is shielded from wind by the fixed roof, and C_{sf} can be neglected or set equal to 1.0 in the case of a drain-dry tank in that there is no free-standing liquid remaining to support ongoing standing idle losses.			

Table 2—Properties of Selected Petroleum Stocks

Petroleum Liquid Mixture	Vapor Molecular Weight	Liquid Molecular Weight	Liquid Density	ASTM D86 Distillation Slope	Vapor Pressure Equation Constants (see Note)		True Vapor Pressure (at 60 °F)
	M_V	M_L	W_L	S	A	B	P_V
	lb/lb-mole	lb/lb-mole	lb/gal	°F/vol %	dimensionless	°R	psia
Motor Gasoline RVP 13	62	92	5.6	3.0	11.644	5,043.6	7.0
Motor Gasoline RVP 10	66	92	5.6	3.0	11.724	5,237.3	5.2
Motor Gasoline RVP 7	68	92	5.6	3.0	11.833	5,500.6	3.5
Jet Naphtha (JP-4)	80	120	6.4	—	11.368	5,784.3	1.3
Jet Kerosene (Jet A)	130	162	7.0	—	12.390	8,933.0	0.008
No. 2 Fuel Oil (Diesel)	130	188	7.1	—	12.101	8,907.0	0.006
No. 6 Fuel Oil	130	387	7.9	—	10.781	8,933.0	0.002
Vacuum Residual Oil	190	387	7.9	—	10.104	10,475.5	0.00004
NOTE True vapor pressure is calculated from: $P_v = \exp \left[A - \frac{B}{(T_L + 459.7)} \right]$ Source: API MPMS Chapter 19.4 ^[21].							



Leg-actuated Type Vacuum-breaker Vent

As the floating roof descends with the withdrawal of stock liquid, the leg of the vacuum-breaker vent contacts the tank bottom before the deck support legs. The floating roof then continues to descend until coming to rest (landing) on the deck support legs. Because the lid of the vacuum-breaker vent had been fixed in position by the longer vacuum-breaker vent leg, it is lifted off the vacuum-breaker opening by the continued descent of the floating roof.

Figure 1—Vacuum-breaker Vent

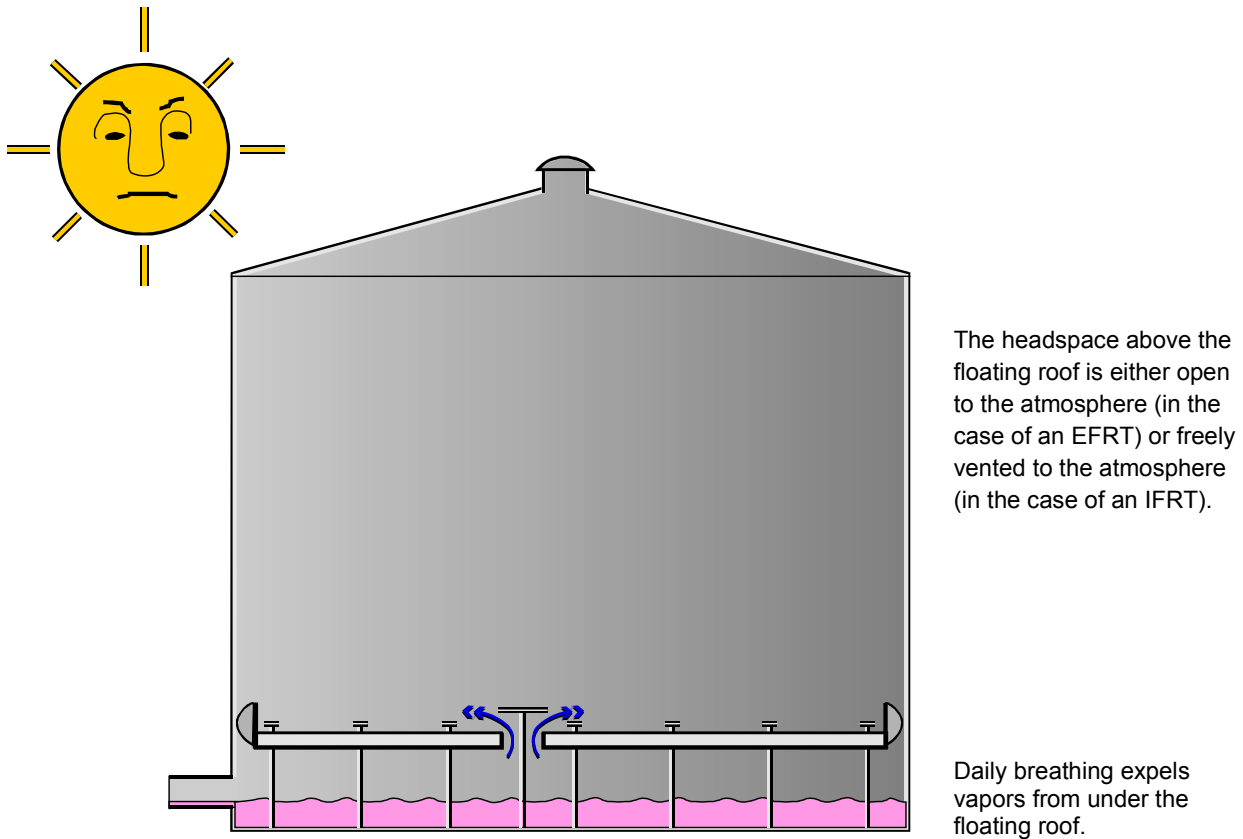


Figure 2—Standing Idle Loss (Emissions)

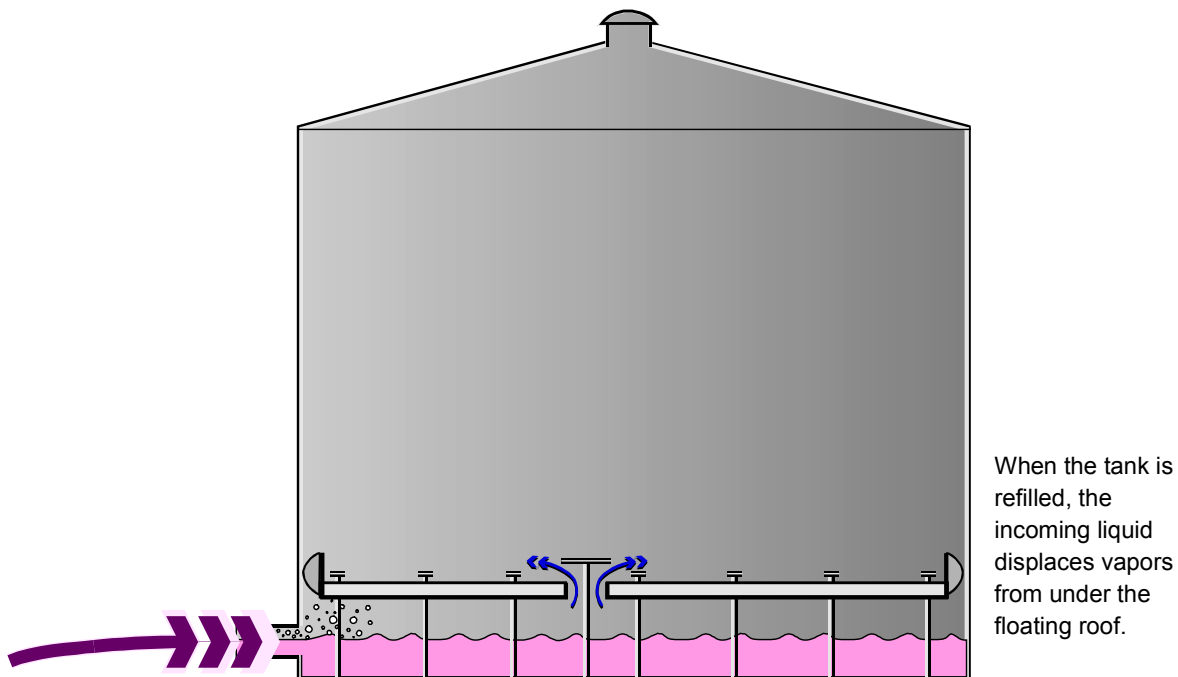


Figure 3—Filling Loss (Emissions)