7.1.3.1 Total Losses From Fixed Roof Tanks[4,8-14] –

The following equations, provided to estimate standing storage and working loss emissions, apply to tanks with vertical cylindrical shells and fixed roofs. These tanks must be substantially liquid- and vapor-tight and must operate approximately at atmospheric pressure. The equations are not intended to be used in estimating losses from unstable or boiling stocks or from mixtures of hydrocarbons or petrochemicals for which the vapor pressure is not known or cannot be readily predicted. Total losses from fixed roof tanks are equal to the sum of the standing storage loss and working loss:

$$L_T = L_S + L_W \qquad (1\text{-}1)$$

where:

L_T = total losses, lb/yr
L_S = standing storage losses, lb/yr, see Equation 1-2
L_W = working losses, lb/yr, see Equation 1-35

7.1.3.1.1 Standing Storage Loss

The standing storage loss, L_S, refers to the loss of stock vapors as a result of tank vapor space breathing. Fixed roof tank standing storage losses can be estimated from Equation 1-2, which comes from the previous edition of Chapter 7 of AP-42.

$$L_S = 365\ V_V\ W_V\ K_E\ K_S \qquad (1\text{-}2)$$

where:

L_S = standing storage loss, lb/yr
V_V = vapor space volume, ft^3, see Equation 1-3
W_V = stock vapor density, lb/ft^3
K_E = vapor space expansion factor, dimensionless
K_S = vented vapor saturation factor, dimensionless
365 = constant, the number of daily events in a year, $(year)^{-1}$

<u>Tank Vapor Space Volume, V_V</u> - The tank vapor space volume is calculated using the following equation:

$$V_V = \left(\frac{\pi}{4} D^2\right) H_{VO} \qquad (1\text{-}3)$$

where:

V_V = vapor space volume, ft^3
D = tank diameter, ft, see Equation 1-13 for horizontal tanks
H_{VO} = vapor space outage, ft, see Equation 1-15

The standing storage loss equation can be simplified by combining Equation 1-2 with Equation 1-3. The result is Equation 1-4.

$$L_S = 365\, K_E \left(\frac{\pi}{4} D^2 \right) H_{VO}\, K_S\, W_V \qquad (1\text{-}4)$$

where:

L_S = standing storage loss, lb/yr
K_E = vapor space expansion factor, dimensionless, see Equation 1-5, 1-6, or 1-7
D = diameter, ft, see Equation 1-13 for horizontal tanks
H_{VO} = vapor space outage, ft, see Equation 1-15; use $H_E/2$ from Equation 1-14 for horizontal tanks
K_S = vented vapor saturation factor, dimensionless, see Equation 1-20
W_V = stock vapor density, lb/ft^3, see Equation 1-21
365 = constant, the number of daily events in a year, (year)$^{-1}$

Vapor Space Expansion Factor, K_E

The calculation of the vapor space expansion factor, K_E, depends upon the properties of the liquid in the tank and the breather vent settings. If the liquid stock has a true vapor pressure greater than 0.1 psia, or if the breather vent settings are higher than the typical range of ±0.03 psig, see Equation 1-7. If the liquid stored in the fixed roof tank has a true vapor pressure less than 0.1 psia and the tank breather vent settings are ±0.03 psig, use either Equation 1-5 or Equation 1-6.

If the tank location and tank color and condition are known, K_E is calculated using the following equation:

$$K_E = 0.0018\, \Delta T_V = 0.0018\ [0.72\, (T_{AX} - T_{AN}) + 0.028\, \alpha \mathrm{I}] \qquad (1\text{-}5)$$

where:

K_E = vapor space expansion factor, dimensionless
ΔT_V = daily vapor temperature range, ER
T_{AX} = daily maximum ambient temperature, ER
T_{AN} = daily minimum ambient temperature,ER
α = tank paint solar absorptance, dimensionless
I = daily total solar insolation on a horizontal surface, Btu/(ft^2 day)
0.0018 = constant, (ER)$^{-1}$
0.72 = constant, dimensionless
0.028 = constant, (ER ft^2 day)/Btu

If the tank location is unknown, a value of K_E can be calculated using typical meteorological conditions for the lower 48 states. The typical value for daily solar insolation is 1,370 Btu/(ft^2 day), the daily range of ambient temperature is 21ER, the daily minimum ambient temperature is 473.5 ER, and the tank paint solar absorptance is 0.17 for white paint in good condition. Substituting these values into Equation 1-5 results in a value of 0.04, as shown in Equation 1-6.

$$K_E = 0.04 \tag{1-6}$$

When the liquid stock has a true vapor pressure greater than 0.1 psia, a more accurate estimate of the vapor space expansion factor, K_E, is obtained by Equation 1-7. As shown in the equation, K_E is greater than zero. If K_E is less than zero, standing storage losses will not occur.

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{\Delta P_V - \Delta P_B}{P_A - P_{VA}} > 0 \tag{1-7}$$

where:

ΔT_V = daily vapor temperature range, °R; see Note 1
ΔP_V = daily vapor pressure range, psi; see Note 2
ΔP_B = breather vent pressure setting range, psi; see Note 3
P_A = atmospheric pressure, psia
P_{VA} = vapor pressure at daily average liquid surface temperature, psia; see Notes 1 and 2 for Equation 1-21
T_{LA} = daily average liquid surface temperature, °R; see Note 3 for Equation 1-21

Notes:

1. The daily vapor temperature range, ΔT_V, is calculated using the following equation:

$$\Delta T_V = 0.72 \Delta T_A + 0.028 \alpha I \tag{1-8}$$

where:

ΔT_V = daily vapor temperature range, °R
ΔT_A = daily ambient temperature range, °R; see Note 4
α = tank paint solar absorptance, dimensionless; see Table 7.1-6
I = daily total solar insolation factor, Btu/ft^2 d; see Table 7.1-7

2. The daily vapor pressure range, ΔP_V, can be calculated using the following equation:

$$\Delta P_V = P_{VX} - P_{VN} \tag{1-9}$$

where:

ΔP_V = daily vapor pressure range, psia
P_{VX} = vapor pressure at the daily maximum liquid surface temperature, psia; see Note 5
P_{VN} = vapor pressure at the daily minimum liquid surface temperature, psia; see Note 5

The following method can be used as an alternate means of calculating ΔP_V for petroleum liquids:

$$\Delta P_V = \frac{0.50\, B\, P_{VA}\, \Delta T_V}{T_{LA}^{\,2}} \qquad (1\text{-}10)$$

where:

ΔP_V = daily vapor pressure range, psia
B = constant in the vapor pressure equation, °R; see Note 2 to Equation 1-21
P_{VA} = vapor pressure at the daily average liquid surface temperature, psia; see Notes 1 and 2 to Equation 1-21
T_{LA} = daily average liquid surface temperature, °R; see Note 3 to Equation 1-21
ΔT_V = daily vapor temperature range, °R; see Note 1

3. The breather vent pressure setting range, ΔP_B, is calculated using the following equation:

$$\Delta P_B = P_{BP} - P_{BV} \qquad (1\text{-}11)$$

where:

ΔP_B = breather vent pressure setting range, psig
P_{BP} = breather vent pressure setting, psig
P_{BV} = breather vent vacuum setting, psig

If specific information on the breather vent pressure setting and vacuum setting is not available, assume 0.03 psig for P_{BP} and -0.03 psig for P_{BV} as typical values. If the fixed roof tank is of bolted or riveted construction in which the roof or shell plates are not vapor tight, assume that $\Delta P_B = 0$, even if a breather vent is used.

4. The daily ambient temperature range, ΔT_A, is calculated using the following equation:

$$\Delta T_A = T_{AX} - T_{AN} \qquad (1\text{-}12)$$

where:

ΔT_A = daily ambient temperature range, °R
T_{AX} = daily maximum ambient temperature, °R
T_{AN} = daily minimum ambient temperature, °R

Table 7.1-7 gives values of T_{AX} and T_{AN} for selected cities in the United States.

5. The vapor pressures associated with daily maximum and minimum liquid surface temperature, P_{VX} and P_{VN}, respectively, are calculated by substituting the corresponding temperatures, T_{LX} and T_{LN}, into the vapor pressure function discussed in Notes 1 and 2 to Equation 1-21. If T_{LX} and T_{LN} are unknown, Figure 7.1-17 can be used to calculate their values.

Diameter

For vertical tanks, the diameter is straightforward. If a user needs to estimate emissions from a horizontal fixed roof tank, some of the tank parameters can be modified before using the vertical tank emission estimating equations. First, by assuming that the tank is one-half filled, the surface area of the liquid in the tank is approximately equal to the length of the tank times the diameter of the tank. Next, assume that this area represents a circle, i.e., that the liquid is an upright cylinder. Therefore, the effective diameter, D_E, is then equal to:

$$D_E = \sqrt{\frac{L\ D}{\frac{\pi}{4}}} \qquad (1\text{-}13)$$

where:

D_E = effective tank diameter, ft
L = length of the horizontal tank, ft (for tanks with rounded ends, use the overall length)
D = diameter of a vertical cross-section of the horizontal tank, ft

By assuming the volume of the tank to be approximately equal to the cross-sectional area of the tank times the length of the tank, an effective height, H_E, of an equivalent upright cylinder may be calculated as:

$$H_E = \frac{\pi}{4} D \qquad (1\text{-}14)$$

D_E should be used in place of D in Equation 1-4 for calculating the standing storage loss (or in Equation 1-3, if calculating the tank vapor space volume). One-half of the effective height, H_E, should be used as the vapor space outage, H_{VO}, in these equations. This method yields only a very approximate value for emissions from horizontal storage tanks. For underground horizontal tanks, assume that no breathing or standing storage losses occur ($L_S = 0$) because the insulating nature of the earth limits the diurnal temperature change. No modifications to the working loss equation are necessary for either above-ground or underground horizontal tanks.

Vapor Space Outage

The vapor space outage, H_{VO} is the height of a cylinder of tank diameter, D, whose volume is equivalent to the vapor space volume of a fixed roof tank, including the volume under the cone or dome roof. The vapor space outage, H_{VO}, is estimated from:

$$H_{VO} = H_S - H_L + H_{RO} \tag{1-15}$$

where:

H_{VO} = vapor space outage, ft; use $H_E/2$ from Equation 1-14 for horizontal tanks
H_S = tank shell height, ft
H_L = liquid height, ft
H_{RO} = roof outage, ft; see Note 1 for a cone roof or Note 2 for a dome roof

Notes:

1. For a cone roof, the roof outage, H_{RO}, is calculated as follows:

$$H_{RO} = 1/3\ H_R \tag{1-16}$$

where:

H_{RO} = roof outage (or shell height equivalent to the volume contained under the roof), ft
H_R = tank roof height, ft

$$H_R = S_R\, R_S \tag{1-17}$$

where:

S_R = tank cone roof slope, ft/ft; if unknown, a standard value of 0.0625 is used
R_S = tank shell radius, ft

2. For a dome roof, the roof outage, H_{RO}, is calculated as follows:

$$H_{RO} = H_R \left[\frac{1}{2} + \frac{1}{6} \left[\frac{H_R}{R_S} \right]^2 \right] \tag{1-18}$$

where:

H_{RO} = roof outage, ft
R_S = tank shell radius, ft
H_R = tank roof height, ft

$$H_R = R_R - \left(R_R^2 - R_S^2 \right)^{0.5} \tag{1-19}$$

where:

H_R = tank roof height, ft
R_R = tank dome roof radius, ft
R_S = tank shell radius, ft

The value of R_R usually ranges from 0.8D - 1.2D, where D = 2 R_S. If R_R is unknown, the tank diameter is used in its place. If the tank diameter is used as the value for R_R, Equations 1-18 and 1-19 reduce to $H_R = 0.268\ R_S$ and $H_{RO} = 0.137\ R_S$.

Vented Vapor Saturation Factor, K_S

The vented vapor saturation factor, K_S, is calculated using the following equation:

$$K_S = \frac{1}{1 + 0.053\, P_{VA}\ H_{VO}} \tag{1-20}$$

where:

K_S = vented vapor saturation factor, dimensionless
P_{VA} = vapor pressure at daily average liquid surface temperature, psia; see Notes 1 and 2 to Equation 1-21
H_{VO} = vapor space outage, ft, see Equation 1-15
0.053 = constant, $(\text{psia-ft})^{-1}$

Stock Vapor Density, W_V - The density of the vapor is calculated using the following equation:

$$W_V = \frac{M_V\ P_{VA}}{R\ T_{LA}} \tag{1-21}$$

where:

W_V = vapor density, lb/ft^3
M_V = vapor molecular weight, lb/lb-mole; see Note 1
R = the ideal gas constant, 10.731 psia ft^3/lb-mole °R
P_{VA} = vapor pressure at daily average liquid surface temperature, psia; see Notes 1 and 2
T_{LA} = daily average liquid surface temperature, °R; see Note 3

Notes:

1. The molecular weight of the vapor, M_V, can be determined from Table 7.1-2 and 7.1-3 for selected petroleum liquids and volatile organic liquids, respectively, or by analyzing vapor samples. Where mixtures of organic liquids are stored in a tank, M_V can be calculated from the liquid composition. The molecular weight of the vapor, M_V, is equal to the sum of the molecular weight, M_i, multiplied by the vapor mole fraction, y_i, for each component. The vapor mole fraction is equal to the partial pressure of component i divided by the total vapor pressure. The partial pressure of component i is equal to the true vapor pressure of component i (P) multiplied by the liquid mole fraction, (x_i). Therefore,

$$M_V = \sum M_i \; y_i = \sum M_i \left(\frac{Px_i}{P_{VA}} \right) \tag{1-22}$$

where:

P_{VA}, total vapor pressure of the stored liquid, by Raoult's Law, is:

$$P_{VA} = \sum Px_i \tag{1-23}$$

For more detailed information, please refer to Section 7.1.4.

2. True vapor pressure is the equilibrium partial pressure exerted by a volatile organic liquid, as defined by ASTM-D 2879 or as obtained from standard reference texts. Reid vapor pressure is the absolute vapor pressure of volatile crude oil and volatile nonviscous petroleum liquids, except liquified petroleum gases, as determined by ASTM-D-323. True vapor pressures for organic liquids can be determined from Table 7.1-3. True vapor pressure can be determined for crude oils using Figures 7.1-13a and 7.1-13b. For refined stocks (gasolines and naphthas), Table 7.1-2 or Figures 7.1-14a and 7.1-14b can be used. In order to use Figures 7.1-13a, 7.1-13b, 7.1-14a, or 7.1-14b, the stored liquid surface temperature, T_{LA}, must be determined in degrees Fahrenheit. See Note 3 to determine T_{LA}.

Alternatively, true vapor pressure for selected petroleum liquid stocks, at the stored liquid surface temperature, can be determined using the following equation:

$$P_{VA} = \exp\left[A - \left(\frac{B}{T_{LA}} \right) \right] \tag{1-24}$$

where:

exp = exponential function
A = constant in the vapor pressure equation, dimensionless
B = constant in the vapor pressure equation, °R
T_{LA} = daily average liquid surface temperature, °R
P_{VA} = true vapor pressure, psia

For selected petroleum liquid stocks, physical property data are presented in Table 7.1-2. For refined petroleum stocks, the constants A and B can be calculated from the equations presented in Figure 7.1-15 and the distillation slopes presented in Table 7.1-4. For crude oil stocks, the constants A and B can be calculated from the equations presented in Figure 7.1-16. Note that in Equation 1-24, T_{LA} is determined in degrees Rankine instead of degrees Fahrenheit.

The true vapor pressure of organic liquids at the stored liquid temperature can be estimated by Antoine's equation:

$$\log\ P_{VA} = A - \left(\frac{B}{T_{LA} + C} \right) \qquad (1\text{-}25)$$

where:

A = constant in vapor pressure equation
B = constant in vapor pressure equation
C = constant in vapor pressure equation
T_{LA} = daily average liquid surface temperature, °C
P_{VA} = vapor pressure at average liquid surface temperature, mm Hg

For organic liquids, the values for the constants A, B, and C are listed in Table 7.1-5. Note that in Equation 1-25, T_{LA} is determined in degrees Celsius instead of degrees Rankine. Also, in Equation 1-25, P_{VA} is determined in mm of Hg rather than psia (760 mm Hg = 14.7 psia).

3. If the daily average liquid surface temperature, T_{LA}, is unknown, it is calculated using the following equation:

$$T_{LA} = 0.44T_{AA} + 0.56T_B + 0.0079\ a\ I \qquad (1\text{-}26)$$

where:

T_{LA} = daily average liquid surface temperature, °R
T_{AA} = daily average ambient temperature, °R; see Note 4
T_B = liquid bulk temperature, °R; see Note 5
α = tank paint solar absorptance, dimensionless; see Table 7.1-6
I = daily total solar insolation factor, Btu/(ft^2 day); see Table 7.1-7

If T_{LA} is used to calculate P_{VA} from Figures 7.1-13a, 7.1-13b, 7.1-14a, or 7.1-14b, T_{LA} must be converted from degrees Rankine to degrees Fahrenheit (°F = °R - 460). If T_{LA} is used to calculate P_{VA} from Equation 1-25, T_{LA} must be converted from degrees Rankine to degrees Celsius (°C = [°R - 492]/1.8). Equation 1-26 should not be used to estimate liquid surface temperature from insulated tanks. In the case of insulated tanks, the average liquid surface temperature should be based on liquid surface temperature measurements from the tank.

4. The daily average ambient temperature, T_{AA}, is calculated using the following equation:

$$T_{AA} = \left(\frac{T_{AX} + T_{AN}}{2} \right) \qquad (1\text{-}27)$$

where:

T_{AA} = daily average ambient temperature, °R
T_{AX} = daily maximum ambient temperature, °R

T_{AN} = daily minimum ambient temperature, °R

Table 7.1-7 gives values of T_{AX} and T_{AN} for selected U.S. cities.

5. The liquid bulk temperature, T_B, is calculated using the following equation:

$$T_B = T_{AA} + 6a - 1 \tag{1-28}$$

where:

T_B = liquid bulk temperature, °R
T_{AA} = daily average ambient temperature, °R, as calculated in Note 4
α = tank paint solar absorptance, dimensionless; see Table 7.1-6.

7.1.3.1.2 Working Loss

The working loss, L_W, refers to the loss of stock vapors as a result of tank filling or emptying operations. Fixed roof tank working losses can be estimated from:

$$L_W = 0.0010\, M_V\, P_{VA}\, Q\, K_N\, K_P \tag{1-29}$$

where:

L_W = working loss, lb/yr
M_V = vapor molecular weight, lb/lb-mole; see Note 1 to Equation 1-21
P_{VA} = vapor pressure at daily average liquid surface temperature, psia; see Notes 1 and 2 to Equation 1-21
Q = annual net throughput (tank capacity [bbl] times annual turnover rate), bbl/yr
K_N = working loss turnover (saturation) factor, dimensionless; see Figure 7.1-18
for turnovers > 36, $K_N = (180 + N)/6N$
for turnovers # 36, $K_N = 1$

N = number of turnovers per year, dimensionless

$$N = \frac{5.614\, Q}{V_{LX}} \tag{1-30}$$

where:

V_{LX} = tank maximum liquid volume, ft^3

$$V_{LX} = \frac{\pi}{4} D^2\, H_{LX} \tag{1-31}$$

where:

D = diameter, ft
H_{LX} = maximum liquid height, ft
K_P = working loss product factor, dimensionless
for crude oils $K_P = 0.75$
for all other organic liquids, $K_P = 1$

Using the following steps, Equation 1-29 can be simplified to combine all variables into one equation.

Using Equation 1-21, the term “$M_V P_{VA}$” can be replaced with Equation 1-32.

$$M_V \, P_{VA} = W_V \, R \, T_{LA} \tag{1-32}$$

Using a combination of Equation 1-30 and Equation 1-31, the term “Q” can be replaced with Equation 1-33.

$$Q = \frac{N \, H_{LX}}{5.614} \left(\frac{\pi}{4} \right) D^2 \tag{1-33}$$

Assuming a standard value of R to be 10.731 ft^3 psia/(lb-mole ER), the result is Equation 1-34.

$$L_W = \left(\frac{0.0010}{5.614} \right) (10.731) \; T_{LA} \; N \; H_{LX} \left(\frac{\pi}{4} \right) D^2 \; K_N \; K_P \; W_V \tag{1-34}$$

By assuming the temperature to be 60EF (520ER), and adding the vent setting correction factor, K_B, the result is Equation 1-35. The vent setting correction factor accounts for any reduction in emissions due to the condensation of vapors prior to the opening of the vent. This correction factor will only affect the calculation if the vent settings are greater than ±0.03 psig.

$$L_W = N \; H_{LX} \left(\frac{\pi}{4} \right) D^2 \; K_N \; K_P \; W_V \; K_B \tag{1-35}$$

where:

L_W = working loss, lb/yr
N = number of turnovers per year, $(\text{year})^{-1}$
H_{LX} = maximum liquid height, ft
D = diameter, ft
K_N = working loss turnover (saturation) factor, dimensionless; see Figure 7.1-18
for turnovers > 36, $K_N = (180 + N)/6N$
for turnovers # 36, $K_N = 1$

K_P = working loss product factor, dimensionless
for crude oils $K_P = 0.75$
for all other organic liquids, $K_P = 1$
W_V = vapor density, lb/ft^3, see Equation 1-21
K_B = vent setting correction factor, dimensionless
for open vents and for a vent setting range up to ± 0.03 psig, $K_B = 1$

Vent Setting Correction Factor

When the breather vent settings are greater than the typical values of ± 0.03 psig, and the condition expressed in Equation 1-36 is met, a vent setting correction factor, K_B, must be determined using Equation 1-37. This value of K_B will be used in Equation 1-35 to calculate working losses.

When:

$$K_N \left[\frac{P_{BP} + P_A}{P_I + P_A} \right] > 1.0 \tag{1-36}$$

Then:

$$K_B = \left[\frac{\dfrac{P_I + P_A}{K_N} - P_{VA}}{P_{BP} + P_A - P_{VA}} \right] \tag{1-37}$$

where:

K_B = vent setting correction factor, dimensionless
P_I = pressure of the vapor space at normal operating conditions, psig
P_A = atmospheric pressure, psia
K_N = working loss turnover (saturation) factor (dimensionless)
for turnovers > 36, $K_N = (180 + N)/6N$
for turnovers ≤ 36, $K_N = 1$
P_{VA} = vapor pressure at the daily average liquid surface temperature, psia; see Notes 1 and 2 to Equation 1-21
P_{BP} = breather vent pressure setting, psig.