

*Insert this on Page 7.1-23 before Section 7.1.3.3*

### Floating Roof Landing Losses<sup>21</sup>

When using floating roof tanks, the roof floats on the surface of the liquid inside the tank and reduces evaporative losses during normal operation. However, when the tank is emptied to the point that the roof lands on deck legs, there is a period where the roof is not floating and other mechanisms must be used to estimate emissions. These emissions continue until the tank is refilled to a sufficient level to again float the roof. Therefore, these emission estimate calculations are applicable each time there is a landing of the floating roof.

The total loss from floating roof tanks during a roof landing is the sum of the standing idle losses and the filling losses. This relationship may be written in the form of an equation:

$$L_{TL} = L_{SL} + L_{FL} \quad (2-10)$$

where:

- $L_{TL}$  = total losses during roof landing, lb/yr
- $L_{SL}$  = standing idle losses during roof landing, lb/yr
- $L_{FL}$  = filling losses during roof landing, lb/yr

The group of applicable equations to estimate the landing losses differs according to the type of floating roof tank that is being used. The equations needed to estimate landing losses from internal floating roof tanks are contained in Table 7.1-17; equations for external floating roof tanks are contained in Table 7.1-18; and equations for drain-dry floating roof tanks are contained in Table 7.1-19. The following sections explain these equations in more detail.

### Standing Idle Losses

After the floating roof is landed and the liquid level in the tank continues to drop, a vacuum is created which could cause the floating roof to collapse. To prevent damage and to equalize the pressure, a breather vent is actuated. Then, a vapor space is formed between the floating roof and the liquid. The breather vent remains open until the roof is again floated, so whenever the roof is landed, vapor can be lost through this vent. These losses are called “standing idle losses.”

The three different mechanisms that contribute to standing idle losses are (1) breathing losses from vapor space, (2) wind losses, and (3) clingage losses. The specific loss mechanism is dependent on the type of floating roof tank.

For internal floating roof tanks with nominally flat bottoms (including those built with a slight upward cone), the breathing losses originate from a discernible level of liquid that remains

in the tank at all times due to the flatness of the tank bottom and the position of the withdrawal line (a liquid “heel”). The liquid evaporates into the vapor space and daily changes in ambient temperature cause the tank to breathe in a manner similar to a fixed roof tank.

For external floating roof tanks, which are not shielded from the surrounding atmosphere, the wind can cause vapors to flow from beneath the floating roof. The higher the wind speeds, the more vapor that can be expelled. These are known as wind losses.

For tanks with a cone-down or shovel bottom, the floor of the tank is sloped to allow for more thorough emptying of the tank contents, therefore, the amount of liquid differs significantly from tanks with flat bottoms (see Figure 7.1-20). When the emptying operation drains the tank bottom, but leaves a heel of liquid in or near the sump, the tank is considered to have a partial heel. A drain-dry condition is attained only when all of the standing liquid has been removed, including from the bottom of the sump. However, due to sludge buildup and roughness of the inside of the tank, a small layer of liquid can remain clinging to the sloped bottom of a drain-dry tank. This layer of liquid will create vapor that can result in clingage losses. The amount of vapor produced within a drain-dry tank is directly related to this clingage. Clingage factors for various tank conditions are contained in Table 7.1-10.

#### Standing Idle Loss for Tanks with a Liquid Heel

A constraint on the standing idle loss is added for floating roof tanks with a liquid heel in that the total emissions cannot exceed the available stock liquid in the tank. This upper limit, represented as  $L_{Smax}$ , is a function of the volume and density of the liquid inside the tank.

$$L_{Smax} = (\text{area of tank})(\text{height of liquid})(\text{density of liquid}) \quad (2-11)$$

Assuming that the tank has a circular bottom and adding a volume conversion unit, the equation can be simplified to Equation 2-12 and Equation 2-13.

$$L_{Smax} = \left(\frac{\pi}{4}\right) D^2 h_{le} W_l \quad (7.48) \quad (2-12)$$

$$L_{Smax} = 5.9 D^2 h_{le} W_l \quad (2-13)$$

where:

- $L_{Smax}$  = limit on standing idle loss, lb per landing episode
- 7.48 = volume conversion factor, gal/ft<sup>3</sup>
- D = diameter of the tank, feet
- $h_{le}$  = effective height of the stock liquid, feet

$W_1 =$  density of the liquid inside the tank, lb/gal

#### Internal Floating Roof Tank with a Liquid Heel

For internal floating roof tanks with liquid heels, the amount of “standing idle loss” depends on the amount of vapor within the vapor space under the floating roof. Essentially, the mechanism is identical to the breathing losses experienced with fixed roof tanks. The mechanism shown in Equation 2-14 is identical to Equation 1-2.

$$L_S = 365 V_V W_V K_E K_S \quad (2-14)$$

where

$L_S =$  annual breathing loss during standing storage, lb/yr

365 = number of days in a year, days/yr

$V_V =$  volume of the vapor space, ft<sup>3</sup>

$W_V =$  stock vapor density, lb/ft<sup>3</sup>

$$W_V = \frac{M_V P}{R T} \quad (2-15)$$

$M_V =$  stock vapor molecular weight, lb/lb-mole

$P =$  true vapor pressure of the stock liquid, psia

$R =$  ideal gas constant, 10.731 (psia-ft<sup>3</sup>)/(lb-mole ER)

$T =$  temperature, ER

$K_E =$  vapor space expansion factor, dimensionless

$K_S =$  saturation factor, dimensionless.

Assuming that  $n_d$  equals the number of days that the tank stands idle and substituting for the stock vapor density according to Equation 2-15, the equation is further simplified to Equation 2-16.

$$L_S = n_d K_E \left( \frac{P V_V}{R T} \right) M_V K_S \quad (2-16)$$

The term with the highest amount of uncertainty is the saturation of the vapor within the tank. The factor,  $K_S$ , is estimated with the same method used to calculate the saturation factor for fixed roof tanks in Equation 1-20. In order to establish limits on the value of  $K_S$ , the

estimated factor is assumed to be less than or equal to the saturation factor during filling (S). (For more information see Filling Losses.)

### External Floating Roof Tank with a Liquid Heel

For external floating roof tanks with a liquid heel, wind affects emission releases from the tanks. As a starting point, begin with a basic equation based on rim-seal loss. The equation, shown as Equation 2-17, is equivalent to Equation 2-2.

$$L_r = (K_{ra} + K_{rb} v^n) D P^* M_v K_c \quad (2-17)$$

where

- $L_r$  = annual rim seal loss, lb/yr
- $K_{ra}$  = zero wind speed rim seal loss factor, lb-mole/ft-yr
- $K_{rb}$  = wind speed dependent rim seal loss factor, lb-mole/((mph)<sup>n</sup>-ft-yr)
- $n$  = seal-related wind speed loss exponent, dimensionless  
( $K_{ra}$ ,  $K_{rb}$ , and  $n$  are specific to a given configuration of rim seal)
- $v$  = average ambient wind speed, mph
- $D$  = tank diameter, ft
- $P^*$  = a vapor pressure function, dimensionless

$$P^* = \frac{\frac{P}{P_a}}{\left(1 + \left[1 - \left(\frac{P}{P_a}\right)\right]^{0.5}\right)^2} \quad (2-18)$$

- $P_a$  = atmospheric pressure, psia
- $P$  = true vapor pressure of the stock liquid, psia
- $M_v$  = stock vapor molecular weight, lb/lb-mole
- $K_c$  = product factor, dimensionless.

Assuming that the stock properties included in the vapor pressure function will adequately account for differences in liquid product type,  $K_c$  is assumed to equal 1. Regardless of the type of rim seal that is in use, it is effectively rendered a 'vapor-mounted' seal when the liquid level falls such that the rim seal is no longer in contact with the liquid. The contribution of a secondary seal is neglected in that it is offset by emissions through the deck fittings. The emissions are therefore based on the case of a welded tank with an average-fitting vapor-mounted primary seal. According to Table 7.1-8, the values of  $K_{ra}$ ,  $K_{rb}$ , and  $n$  are 6.7, 0.2, and 3.0, respectively. The variables were substituted and the equation was converted from annual emissions to daily emissions by dividing the equation by 365. A value of 10 mph is assigned to the wind speed, so that estimated standing idle losses from an external floating roof tank will not be less than for a typical internal floating roof tank. Lower values for the rim seal loss factors or

the wind speed should not be used. The equation can be simplified for daily emissions to Equation 2-19.

$$L_{\text{Swind}} = 0.57 n_d D P^* M_V \quad (2-19)$$

where:

- $L_{\text{Swind}}$  = daily standing idle loss due to wind, lb per day
- $n_d$  = number of days that the tank is standing idle, days
- $D$  = tank diameter, ft
- $P^*$  = a vapor pressure function, dimensionless
- $M_V$  = stock vapor molecular weight, lb/lb-mole

After the wind empties the vapor space above the remaining liquid heel, the liquid will continue to produce vapor. Thus, this standing idle loss will occur every day that the tank stands idle. This equation is adequate at this time, but could be revised as additional testing is conducted and studied.

#### Standing Idle Losses from Drain-Dry Tanks

When a drain-dry tank has been emptied, the only stock liquid available inside the tank is a small amount that clings to the wetted surface of the tank interior (if a heel of liquid remains in or near a sump, then the tank should be evaluated as having a partial heel, and not as drain dry – see Figure 7.1-20). The slope prevents a significant amount of stock liquid from remaining in the tank so that evaporation is much lower than from tanks with liquid heels. Due to the limited amount of liquid clinging to the interior of the tank, as shown in Figure 7.1-20, it is assumed that vapors would not be replenished as readily as in tanks with a liquid heel. For this model, standing idle loss due to clingage is a one-time event rather than a daily event.

The loss due to clingage is proportional to a clingage factor, which varies with the condition of the inside of the tank. A list of clingage factors are shown in Table 7.1-10. The factors are given in terms of barrels per thousand square feet. To convert the loss to pounds, the density of the liquid and the area of the tank must be taken into account, as shown in Equation 2-20.

$$L_C = 0.042 C W_1 (\text{Area}) \quad (2-20)$$

where:

- $L_C$  = clingage loss from the drain-dry tank, lb
- 0.042 = conversion factor between gallons and square feet, gal/ft<sup>2</sup>
- $C$  = clingage factor, dimensionless
- $W_1$  = density of the liquid, lb/gal
- Area = area of the tank bottom, ft<sup>2</sup>

$$Area = \left( \frac{\pi D^2}{4} \right) \quad (2-21)$$

Among the conditions shown in Table 7.1-10, the one that best approximates a sludge-lined tank bottom is gunite-lined. Assuming that gasoline is being stored in the tank, a clingage factor of 0.15 and the area term in Equation 2-21 were substituted into Equation 2-20, which simplifies to Equation 2-22.

$$L_S = 0.0063 W_l \frac{\pi D^2}{4} \quad (2-22)$$

The clingage loss should be constrained by an upper limit equal to the filling loss for an internal floating roof tank with a liquid heel. This is demonstrated in Equation 2-23.

$$L_{S\max} = 0.60 \left( \frac{P V_V}{R T} \right) M_V \quad (2-23)$$

where:

- $L_{S\max}$  = maximum standing idle loss for drain-dry tanks due to clingage, lb
- $W_l$  = density of the liquid inside the tank, lb/gal
- $D$  = diameter of the tank, feet
- $P$  = true vapor pressure of the liquid inside the tank, psia
- $V_V$  = volume of the vapor space, ft<sup>3</sup>
- $R$  = ideal gas constant, 10.731 psia ft<sup>3</sup> /lb-mole ER
- $T$  = average temperature of the vapor and liquid below the floating roof, ER
- $M_V$  = stock vapor molecular weight, lb/lb-mole

Therefore, the standing idle loss for drain-dry tanks, shown in Equation 2-22, must be less than or equal to Equation 2-23. This relationship is shown by Equation 2-24.

$$L_S \leq 0.60 \left( \frac{P V_V}{R T} \right) M_V \quad (2-24)$$

### Filling Losses

When a floating roof tank is refilled, there are additional emissions resulting from the roof being landed. These losses are called “filling losses” and continue until the liquid reaches the level of the floating roof.

The first contributor to filling losses is called the “arrival” component. As liquid flows into the tank, the vapor space between the liquid and the floating roof is decreased. The

displaced vapors are expelled through the breather vent. Once the roof is refloated on the liquid surface, the breather vent closes.

The second contributor to filling losses is called the “generated” component. As the incoming liquid evaporates, additional vapors will be formed in the vapor space and will also be expelled through the breather vent.

#### Internal Floating Roof Tank with a Liquid Heel

For internal floating roof tanks with a liquid heel, the amount of vapor that is lost during filling is directly related to the amount of vapor space and the saturation level of the vapor within the vapor space, as shown in Equation 2-25.

$$L_F = (\text{vol of vapor space})(\text{density of vapor})(\text{mol wt of vapor})(\text{satfactor}) \quad (2-25)$$

After substituting for the major terms in Equation 2-25, the equation can be simplified to Equation 2-26.

$$L_F = \left( \frac{P V_V}{R T} \right) M_V S \quad (2-26)$$

where:

- $L_F$  = filling loss, lb
- $P$  = true vapor pressure of the liquid within the tank, psia
- $V_V$  = volume of the vapor space, ft<sup>3</sup>
- $R$  = ideal gas constant, 10.731 psia-ft<sup>3</sup>/(lb-mole-ER)
- $T$  = average temperature of the vapor and liquid below the floating roof, ER
- $M_V$  = stock vapor molecular weight, lb/lb-mole
- $S$  = filling saturation factor, dimension less (0.60 for a full liquid heel; 0.50 for a partial liquid heel).

This equation accounts for the arrival losses and the generated losses. The main concern with this equation is the estimation of the saturation factor. All other components are based on the ideal gas laws. For consistency, an accepted value of 0.6, which is used elsewhere in Chapter 7, will be used for the case of a full liquid heel. A value of 0.5 has been demonstrated for the case of a partial liquid heel.

#### External Floating Roof Tank with a Liquid Heel

For external floating roof tanks with a liquid heel, the amount of vapor lost during filling will be less than the amount for internal floating roof tanks because of wind effects. The “arrival” component will be partially flushed out of the tank by the wind, so the preceding equation requires the addition of a correction factor,  $C_{sf}$  to the saturation factor as shown in Equation 2-27.

$$L_F = \left( \frac{P V_V}{R T} \right) M_V (C_{sf} S) \quad (2-27)$$

The basic premise of the correction factor is that the vapors expelled by wind action will not be present in the vapor space when the tank is refilled, so the amount of saturation is lowered. This is demonstrated in Equation 2-28.

$$C_{sf} = 1 - \frac{(\text{one day of wind driven standing idle loss}) - (\text{one day without wind standing idle loss})}{\text{one day without wind total loss}} \quad (2-28)$$

The equation for the saturation factor can be simplified based on other equations contained in this section as shown in Equation 2-29 and Equation 2-30.

$$C_{sf} = 1 - \left( \frac{(\text{Equation 2-19}) - (\text{Equation 2-16})}{(\text{Equation 2-16}) + (\text{Equation 2-26})} \right) \quad (2-29)$$

$$C_{sf} = 1 - \left( \frac{\left( (0.57 n_d D P^* M_V) - \left( n_d K_E \left( \frac{P V_V}{R T} \right) M_V K_S \right) \right)}{\left( n_d K_E \left( \frac{P V_V}{R T} \right) M_V K_S \right) + \left( M_V S \left( \frac{P V_V}{R T} \right) \right)} \right) \quad (2-30)$$

where:

- $C_{sf}$  = filling saturation correction factor, dimensionless
- $n_d$  = number of days the tank stands idle with the floating roof landed, dimensionless
- $K_E$  = vapor space expansion factor, dimensionless

$$K_E = \frac{\Delta T_V}{T} \left( 1 + \frac{0.50 B P}{T(P_a - P)} \right) \quad (2-31)$$

where:

- $\Delta T_V$  = daily vapor temperature range, ER
- $T$  = average temperature of the vapor and liquid below the floating roof, ER
- $B$  = constant from the vapor pressure equation shown in Equation 1-24, ER
- $P$  = true vapor pressure of the stock liquid, psia
- $P_a$  = atmospheric pressure at the tank location, psia

$V_V =$  volume of the vapor space, ft<sup>3</sup>

$$V_V = \frac{h_v \pi D^2}{4} \quad (2-32)$$

where:

$h_v =$  height of the vapor space under the floating roof, ft

$D =$  tank diameter, ft

$R =$  ideal gas constant, 10.731 psia ft<sup>3</sup> / lb-mole R

$M_V =$  stock vapor molecular weight, lb/lb-mole

$K_S =$  standing idle saturation factor, dimensionless

$S =$  filling saturation factor, dimensionless

$P^* =$  vapor pressure function, dimensionless

$W_1 =$  stock liquid density, lb/gal

### Drain-Dry Tanks

The “arrival” component of filling losses for drain-dry tanks is completely covered by the “clingage” loss. Once this initial loss occurs, there is no remaining liquid inside the tank. Therefore, there is no vapor in the tank that could be expelled by the incoming liquid.

However, the “generated” component remains a valid aspect of the model. Therefore, the filling loss calculations for drain-dry tanks are identical to the filling loss calculations for internal floating roof tanks with a liquid heel. Although the equations are the same, the saturation factor will be lower for drain-dry tanks due to the lack of an “arrival” component. AP-42 Chapter 5, *Petroleum Industry*, provides emission factors for the loading of gasoline and crude oil into compartments according to the prior state of the compartment. A drain-dry tank would be most similar to a tank that was cleaned before filling because a cleaned tank also lacks “arrival” losses. The emission factor (0.33 lb/1000 gallons) for this kind of tank can be converted to a saturation factor by assuming a pressure of 8 psia (the same assumption used in the formulation of the emission factor), and substituting the molecular weight of gasoline (64 lb/lb-mole). The resulting saturation factor is 0.15. The equation is the same as Equation 2-26 with a different assumed saturation factor.

$$L_F = \left( \frac{P V_V}{R T} \right) M_V S \quad (2-26)$$

where:

$L_F =$  filling loss, lb

$P =$  true vapor pressure of the liquid within the tank, psia

$V_V =$  volume of the vapor space, ft<sup>3</sup>

$R =$  ideal gas constant, 10.731 psia-ft<sup>3</sup>/(lb-mole-ER)

$T =$  average temperature of the vapor and liquid below the floating roof, ER

$M_V =$  stock vapor molecular weight, lb/lb-mole

$S =$  filling saturation factor, dimension less (0.15 for a drain-dry tank).

Table 7.1-17. Roof Landing Losses for Internal Floating Roof Tank with a Liquid Heel

Standing Idle Loss	$L_S = \frac{P V_V}{R T} n_d K_E M_V K_S$ <p style="text-align: right;">Equation 2-16</p> $L_S \leq 5.9 D^2 h_{le} W_l$ <p style="text-align: right;">Equation 2-13</p>
Standing Idle Saturation Factor	$K_S = \frac{1}{1 + 0.053 (P h_v)}$ <p style="text-align: right;">Equation 1-20</p> $K_S \leq S$
Filling Loss Equation	$L_F = \left( \frac{P V_V}{R T} \right) M_V S$ <p style="text-align: right;">Equation 2-26</p>
Filling Saturation Factor (S)	<p>S = 0.60 for a full liquid heel</p> <p>S = 0.50 for a partial liquid heel</p>

Table 7.1-18. Roof Landing Losses for External Floating Roof Tank with a Liquid Heel

Standing Idle Loss	$L_S = 0.57 n_d D P^* M_V$ $L_S \leq 5.9 D^2 h_{le} W_l$	<p>Equation 2-19</p> <p>Equation 2-13</p>
Standing Idle Saturation Factor	Not applicable	
Filling Loss Equation	$L_F = \left( \frac{P V_V}{R T} \right) M_V (C_{sf} S)$	<p>Equation 2-27</p>
Filling Saturation Factor (S)	$C_{sf} = 1 - \frac{\left( (0.57 n_d D P^* M_v) - \left( n_d K_E \left( \frac{P V_V}{R T} \right) M_V K_S \right) \right)}{\left( n_d K_E \left( \frac{P V_V}{R T} \right) M_V K_S \right) + \left( M_V S \left( \frac{P V_V}{R T} \right) \right)}$ <p>S = 0.6 for a full liquid heel S = 0.5 for a partial liquid heel</p> $C_{sf} S \geq 0.15$	

Table 7.1-19. Roof Landing Losses for All Drain-Dry Tanks

Standing Idle Loss	$L_S = 0.0063 W_l \left( \frac{\pi D^2}{4} \right)$ <p style="text-align: right;">Equation 2-22</p> $L_S \leq 0.60 \left( \frac{P V_V}{R T} \right) M_V$ <p style="text-align: right;">Equation 2-23</p>
Standing Idle Saturation Factor	Not applicable
Filling Loss Equation	$L_F = \left( \frac{P V_V}{R T} \right) M_V S$ <p style="text-align: right;">Equation 2-26</p>
Filling Saturation Factor (S)	S = 0.15

where:

$L_s$  = standing idle loss per episode (lb)

$n_d$  = number of days the tank stands idle with the floating roof landed (dimensionless)

$K_E$  = vapor space expansion factor (dimensionless)

$$K_E = \frac{\Delta T_V}{T} \left( 1 + \frac{0.50 B P}{T(P_a - P)} \right)$$

)  $T_V$  = daily vapor temperature range (ER)

$T$  = average temperature of the vapor and liquid below the floating roof (ER)

$B$  = constant from the vapor pressure equation shown in Equation 1-24 (ER)

$P$  = true vapor pressure of the stock liquid (psia)

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

$V_V$  = volume of the vapor space (ft<sup>3</sup>)

$$V_V = \frac{h_v \pi D^2}{4}$$

$h_v$  = height of the vapor space under the floating roof (ft)

$D$  = tank diameter (ft)

$R$  = ideal gas constant (psia ft<sup>3</sup> / lb-mole R) = 10.731

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

$K_S$  = standing idle saturation factor (dimensionless)

$S$  = filling saturation factor (dimensionless)

$P^*$  = vapor pressure function (dimensionless)

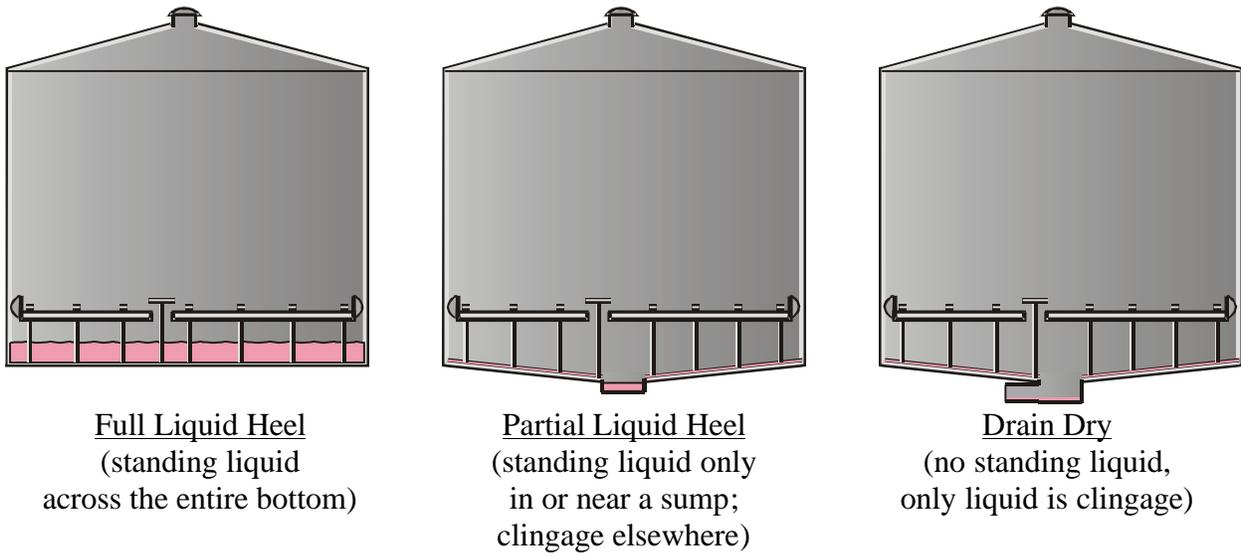
$$P^* = \frac{\frac{P}{P_a}}{\left( 1 + \left[ 1 - \left( \frac{P}{P_a} \right) \right]^{0.5} \right)^2}$$

$W_l$  = stock liquid density (lb/gal)

$h_{le}$  = effective height of the stock liquid (ft)

$L_F$  = filling loss per episode (lb)

$C_{sf}$  = filling saturation correction factor (dimensionless)



**Figure 7.1-20 Bottom conditions for landing loss.<sup>20</sup>**

{replacement for Figure 7.1-1 currently on Page 7.1-30}

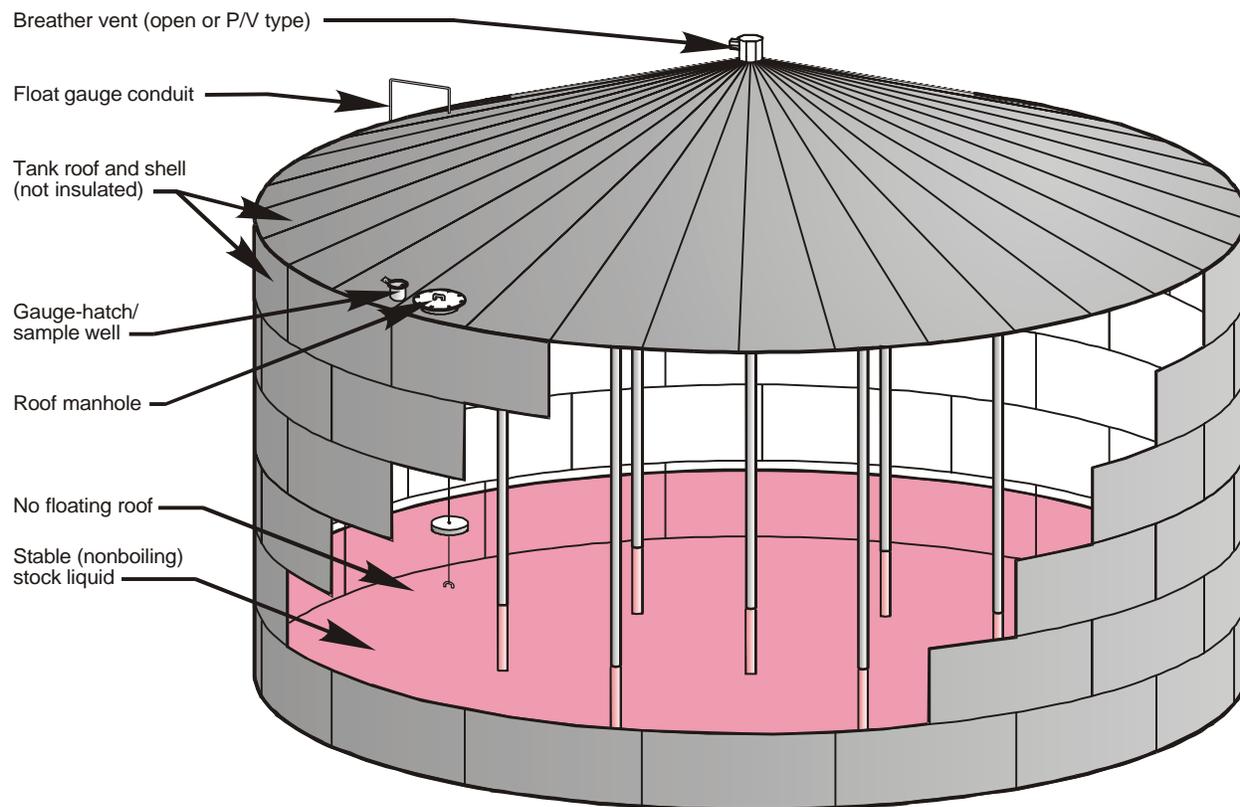


Figure 7.1-1 Typical fixed-roof tank.<sup>20</sup>

{A new reference was added for the landing loss section (21); technically the references should be re-numbered, but that would entail a completely new Chapter 7}

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