CHAPTER III

Evaporation Loss Calculation

This chapter contains procedures for estimating total evaporation stock losses and / or the equivalent total atmospheric hydrocarbon emissions from volatile stocks stored in fixed roof tank, internal floating roof tank and external floating roof tank, which is already demonstrated in section 3.1, 3.2 and 3.3 respectively.

The equations presented are based on recent laboratory, test tank and field tank data. These equations are used to estimate annual losses of general equipment types for various liquid stocks, stock vapor pressures, tank sizes, meteorological conditions and operating conditions. The general equation for calculating total loss, L_T, for all three types of storage tanks, is the sum of standing storage loss, L_S, and the working or withdrawal loss, L_W.

$$L_T = L_S + L_W$$

L_T = Total loss, in pounds per year or barrels per year

L_S = Standing storage loss, in pounds per year or barrels per year

L_W = Working or withdrawal loss, in pounds per year or barrels per year

3.1 Loss Equations for Fixed-Roof Tanks [1]

3.1.1 Standing Storage Loss, L_S

The following minimum information is needed for calculating standing storage loss, L_S:

a) tanks diameter

b) tank shell height

c) tank roof type (cone roof or dome roof)

d) tanks outside paint color

e) tank location

f) stock type

g) stock liquid bulk temperature

h) stock vapor pressure (or the stock Reid vapor pressure)

I) stock liquid level

Improved estimates of the standing storage loss can be obtained using some or all of the following additional information.

a) tank cone roof slope or dome roof radius

b) breather vent pressure and vacuum settings

c) daily average ambient temperature

d) daily ambient temperature range

e) daily total solar isolation on a horizontal surface

f) atmospheric pressure

g) molecular weight of the stock vapor

h) stock liquid surface temperature

Standing storage loss, L_S , pertains to evaporation of liquid stock which occurs as a result of tank vapor space breathing. The standing storage loss can be estimated from the equation (1-1) :

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

Where V_V, W_V, K_E and K_S are calculated from Equation (1-2) through (1-5), respectively.

Tank Vapor Space Volume, V_V

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

Stock Vapor Density, W_V

$$W_V = \frac{M_v P_{va}}{R T_{la}} \qquad (1\text{-}3)$$

Vapor Space Expansion Factor, K_E

$$K_E = \frac{DT_v}{T_{la}} + \frac{DP_v - DP_b}{P_a - P_{va}} \qquad (1\text{-}4)$$

Vented Vapor Saturation Factor, K_S

$$K_S = \frac{1}{1 + 0.053 P_{va} H_{vo}} \qquad (1\text{-}5)$$

Where:

L_S	=	standing storage loss, in pounds per year
V_V	=	tank vapor space volume, in cubic feet
W_V	=	stock vapor density, in pounds per cubic foot
K_E	=	vapor space expansion factor (dimensionless)
K_S	=	vented vapor saturation factor (dimensionless)
D	=	tank diameter, in feet
H_{VO}	=	vapor space outage, in feet
M_V	=	stock vapor molecular weight, in pounds per pound-mole

P_{va} = stock vapor pressure at the daily average liquid surface temperature, in pounds per square inch absolute

R = ideal gas constant (10.731), in (pounds per square inch absolute) cubic feet per pound-mole degree Rankine

T_{la} = daily average liquid surface temperature, in degrees Rankine

ΔT_v = daily vapor temperature range, in degrees Rankine

ΔP_v = stock daily vapor pressure range, in pounds per square inch.

ΔP_b = breather vent pressure setting range, in pounds per square inch.

P_a = atmospheric pressure, in pounds per square inch absolute

Unit of a constant, 365, in Equation 1 is $year^{-1}$

Unit of a constant, 0.053, in Equation 1 is $(\text{<pounds per square inch absolute > feet})^{-1}$

3.1.2 Working Loss , L_W

Working loss can be calculated from the following information:

a) stock vapor molecular weight

b) stock vapor pressure (or the stock Reid vapor pressure)

c) stock annual net throughput (associated with increasing the stock liquid level)

d) stock turnover rate

e) stock type

Working loss, L_W, pertains to evaporation of liquid stock which occurs as a result of tank filling or emptying operations. Working loss can be estimated from Equation (1-6) :

$$L_W = 0.0010\, M_V\, P_{va} Q\, K_N\, K_P \qquad (1\text{-}6)$$

Where :

L_W	=	Working loss, in pounds per year
M_V	=	stock vapor molecular weight, in pounds per pound-mole
P_{va}	=	stock vapor pressure at the daily liquid surface temperature, in pounds per square inch absolute
Q	=	stock annual net throughput (associated with increasing the stock liquid level in the tank), in barrels per year
K_N	=	working loss turnover factor (dimensionless)
K_P	=	working loss product factor (dimensionless)

Unit of a constant, 0.0010, in Equation (1-6) is pound-mole per (pounds per square inch absolute) barrel.

3.2 Loss Equation for Internal Floating-Roof Tanks [2]

3.2.1 Standing Storage Loss

The minimum information needed for calculating standing storage loss, L_s, includes:

a) stock true vapor pressure (or Reid vapor pressure and average stock storage temperature)

b) stock type

c) tank diameter

d) tank type (column supported or self-supported fixed roof)

Improved estimates of standing storage loss can be obtained using some or all of the following additional information:

a) rim seal system type

b) deck fitting and number

c) floating deck construction details (welded or bolted seams; length of bolted deck seams)

d) stock vapor molecular weight

Standing storage loss, L_s, which includes losses from the rim seal area, the deck fittings, and the deck seams, can be estimated from equation (2-1):

$$L_s = [(K_r D) + (F_f) + (F_d)] P^* M_v K_c \qquad (2\text{-}1)$$

where:

L_s	=	standing storage loss (lb/yr)
K_r	=	rim seal loss factor (lb-mole/ft yr)
D	=	tank diameter (ft)
F_f	=	total deck fitting loss factor (lb-mole/yr)
F_d	=	deck seam loss factor (lb-mole/yr)
P^*	=	vapor pressure function (dimensionless)
M_v	=	average stock vapor molecular weight (lb/lb-mole)
K_c	=	product factor (dimensionless)

Equation 2.1 is derived by combining three equations representing the independent contributions of rim seal area, deck fitting, and deck seams to total standing storage loss. The following equations can be use to estimate these independent contributions:

$$L_r = (K_r D) P^* M_v K_c \quad (2\text{-}2)$$

$$L_f = (F_f) P^* M_v K_c \quad (2\text{-}3)$$

$$L_d = (F_d) P^* M_v K_c \quad (2\text{-}4)$$

where:

L_r = rim seal loss (lb/yr)

L_f = total deck fitting loss (lb/yr)

L_d = deck seam loss (lb/yr)

Other variables are as defined for equation (2-1)

3.2.2 Withdrawal Loss

Withdrawal loss, L_w, can be calculated from the following information:

a) annual net throughput (associated with lowering the liquid stock level in the tank)
b) stock type
c) average liquid stock density
d) tank diameter
e) tank shell and column condition

A slight improvement of withdrawal loss estimate can be riented if type and number of columns are known for the particular tank under consideration.

Withdrawal loss, L_W, includes evaporation of liquid stock that clings to the tank shell and to the column while stock withdrawal loss can be estimated from equation (2-5):

$$L_W \quad = \quad \frac{(0.093)QCW_l}{D}\,[1+(N_cF_c\,/\,D)] \qquad (2\text{-}5)$$

Where:

L_W	=	withdrawal loss (lb/yr)
Q	=	annual net throughput (associated with lowering the liquid stock level in the tank) (bbl/yr)
C	=	clingage factor (bbl/1000 ft^2)
W_l	=	average liquid stock density at average storage temperature (lb/gal)
D	=	tank diameter (ft)
N_c	=	number of columns (dimensionless)
F_c	=	effective column diameter (ft)

The constant, 0.943, has dimensions of [1000 ft^3 * (gal/bbl^2]

3.3 Loss Equation for External Floating-Roof Tanks [3]

3.3.1 Standing Storage Loss

The minimum information needed for calculating the standing storage loss, L_S, includes:

a) stock true vapor pressure (or Reid vapor pressure and average stock storage temperature)

b) stock type

c) tank diameter

d) tank type (column supported or self-supported fixed roof)

Improved estimates of standing storage loss can be obtained using some or all of the following additional information:

a) type of tank construction (welded or riveted)

b) rim seal system type

c) roof fitting and number

d) floating-roof construction details (pontoon or double-deck)

e) stock vapor molecular weight

Standing storage loss, L_S, includes losses from rim seal area, deck fittings, and deck seams. Standing storage loss can be estimated from equation (3-1):

$$L_S = [(F_r D) + F_f] P^* M_V K_C \qquad (3\text{-}1)$$

where:

L_S	=	standing storage loss (lb/yr)
F_r	=	rim-seal loss factor (lb-mole/ft yr)
D	=	tank diameter (ft)
F_f	=	total roof-fitting loss factor (lb-mole/yr)
P^*	=	vapor pressure function (dimensionless)
M_V	=	average stock vapor molecular weight (lb/lb-mole)
K_C	=	product factor (dimensionless)

Equation 3.1 is derived by combining three equations representing the independent contributions of rim seal area, deck fitting to total standing storage

loss. The following equations can be use to estimate these independent contributions:

$$L_r = (K_r D) P^* M_v K_c \qquad (3\text{-}2)$$

$$L_f = (F_f) P^* M_v K_c \qquad (3\text{-}3)$$

where:

L_r = rim seal loss (lb/yr)

L_f = total deck fitting loss (lb/yr)

The other variables are as defined for equation (3-1).

3.3.2 Withdrawal loss

Withdrawal loss, L_W, can be calculated from the following information:

- annual net thruput (associated with lowering the liquid stock level in the tank)
- stock type
- average liquid stock density
- tank diameter
- tank shell condition

Withdrawal loss, L_W, pertains to evaporation of liquid stock that clings to the tank shell while the stock is withdrawn. Withdrawal loss can be estimated from equation (3-4):

$$L_W = \frac{(0.093)QCW_l}{D} \qquad (3\text{-}4)$$

Where:

L_W = withdrawal loss (lb/yr)

Q = annual net throughput (associated with lowering the liquid stock level in the tank) (bbl/yr)

C = clingage factor (bbl/1000 ft^2)

W_l = average liquid stock density at average storage temperature (lb/gal)

D = tank diameter (ft)

Unit of a constant, 0.943, in equation (3-5) is 1000 ft^3 * (gal/bbl)^2.

3.4 Unit Conversion

a) Standing storage loss is converted from pounds per year to barrels per year as follows:

$$L_S(\text{barrels per year}) = \frac{L_s}{42W_{vc}} \; (L_S : \text{pounds per year}) \qquad (4)$$

Where

W_{VC} = stock condensed vapor density at 60 ^{o}F , in pounds per gallon.

Unit of a constant, 42, in equation 4 is gallons per barrel.

b) Working or withdrawal loss are converted from pounds per year to barrels per year as follows:

$$L_W(\text{barrels per year}) = \frac{L_w}{42W_{vc}} \; (L_W\text{: pounds per year}) \qquad (5)$$

Where:

W_{vc} = stock condensed vapor density at 60 ^{o}F , in pounds per gallon.

Unit of a constant, 42 , in Equation 5 is gallons per barrel.