EVAPORATION LOSS MEASUREMENT FROM STORAGE TANKS

Class # 2150.1

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INTRODUCTION

Evaporation from fixed and floating roof storage tanks is a major source of product loss in the crude oil industry. Evaporation is a natural phenomenon describing when a liquid turns into a gas. A liquid will tend to evaporate depending on its vapor pressure. A liquid's vapor pressure is dependent on the surface temperature and composition of the liquid. Evaporation losses should be minimized to help maximize company revenue, meet regulatory requirements, and reduce greenhouse gas emissions. The United States Environmental Protection Agency (EPA), state, and local governments are implementing stricter regulations on volatile organic compounds (VOC's) and greenhouse gas (GHG) emissions which result from storage tank evaporation. The accurate quantification of evaporative losses from storage tanks is imperative given the impact to the company's bottom line and the environment. The American Petroleum Institute Manual of Petroleum Measurement Standards (API MPMS) Chapter 19 details equations for estimating the average annual evaporation loss from storage tanks. These equations are based on test tank and field tank data and have been revised since initial publication for more accurate estimations.

WHAT IS EVAPORATION?

Evaporation is when a substance changes from the liquid phase to the vapor phase (at conditions that do not result in boiling). Evaporation occurs when molecules in the liquid substance have enough kinetic energy to overcome the intermolecular forces in the liquid phase. The tendency for a substance to evaporate is dependent on the liquid's volatility and temperature. Volatility is a material property that describes how readily a liquid enters the gaseous phase. The volatility of a liquid is quantified by its vapor pressure. The vapor pressure of a substance is the pressure of its gaseous phase when it is in equilibrium with its liquid phase. The higher the vapor pressure of a liquid the more volatile the liquid and thus has a higher tendency to evaporate. Different liquids have different vapor pressures at the same temperature, but all liquids become more volatile with increasing temperature. The higher the liquid's temperature, the higher the average kinetic energy of the molecules in the liquid, increasing the vapor pressure and resulting in a greater rate of evaporation.

EVAPORATION FROM CRUDE OIL AND CONDENSATE

Crude oil and condensate are multi-component liquids made up of a wide range of hydrocarbons that have different volatilities. In addition, the composition of crude oil and condensate will be different for each well. Therefore, evaluating the evaporative losses from crude oil and condensate is challenging because the composition of the liquid mixture must be known and no two storage tanks carry the "same" liquid mixture.

Crude oil and condensates are typically classified by their density, which is measured by API gravity. Crude oil and condensate with a low density (high API gravity) typically consist of smaller hydrocarbons and have higher vapor pressures, and hence are more volatile. High API gravity crude oil or condensate is primarily composed of hydrocarbons with fewer carbon atoms than C20. Heavy crude oil has a low API gravity and low vapor pressure, and hence is less volatile. Heavy crude oils are primarily composed of C40+ hydrocarbons. For any crude oil or condensate mixture its composition determines its API gravity, which in turn is a good indicator of its volatility or tendency to evaporate.

The evaporation rate of crude oil and condensate is logarithmic over time because the more volatile components evaporate first at high rates followed by the less volatile components. The lighter molecules evaporate first leaving the heavier molecules behind causing a reduction in the rate of evaporation with time, typical of a logarithmic trend.

EVAPORATION IN STORAGE TANKS

Evaporation in crude oil and condensate storage tanks leads to lost saleable product, air pollution, and greenhouse gas emissions. Storage tanks store produced crude oil and condensate at near-atmospheric pressure. Produced gas or oil from the wellhead typically passes through at least a separator and sometimes a heater-treater depending on the quality of the gas/oil. The separated liquids from the separator and heater-treater are dumped to storage tanks. Once the liquids have settled in the storage tank, gases from evaporation are contained in the tank until the pressure in the tank exceeds the set point on the tank vents.[1] Evaporative losses occur primarily in two ways: standing losses and working losses. The total evaporative loss from any storage tank is the sum of the **standing losses, L_S,** and the **working losses, L_W.**

$$L_T \textit{ (pounds per year)} = L_S + L_W$$

Standing losses result from the thermal expansion and contraction of the tank and vapor mixture from the daily heating cycle. As the temperature increases during the day, the air-vapor mixture expands and increases the pressure in the tank. If the pressure in tank exceeds the set points on the tank vents, vapor is vented from the tank resulting in evaporative losses. Standing losses occurs without any change in liquid level in the tank. The standing losses are a function of the following:

- Tank shell height
- Tank diameter
- Roof outage - volume contained under a cone roof or dome roof
- Liquid height
- Liquid surface temperature
- Vapor pressure
- Vent settings

Working losses result from the change in liquid level in the tank. When the liquid level increases, the vapor in the tank is compressed increasing the pressure in the tank. If the pressure in the tank exceeds the set point on the tank vents, vapor is vented from the tank resulting in evaporative losses. Working losses are a function of the following:

- Stock turnover rate
- Annual throughput
- Tank diameter
- Liquid height
- Liquid surface temperature
- Vent settings
- Vapor density
- Vapor pressure

There are several types of storage tanks. Two common storage tank types for crude oil and condensate are fixed roof tanks and floating roof tanks. Established methodologies for quantifying evaporative losses from each storage tank type are described below.

[1] Tank vents are generally mounted on the tank roof and protect the tank from overpressure or over vacuum. When pressure in the tank vapor space inside the tank exceeds the pressure set point, the pressure-vacuum vent opens to release the vapors until the pressure is reduced below this set point. If a vacuum is formed in the tank, the vent opens to allow air to enter the tank until the vacuum is reduced below the set point.

Fixed Roof

A fixed roof tank is an enclosed tank with a roof, but does not have a lid floating directly on the liquid surface. Vapors accumulate in the space between the tank roof and the liquid surface. Figure 1 shows a diagram of a typical fixed roof storage tank.

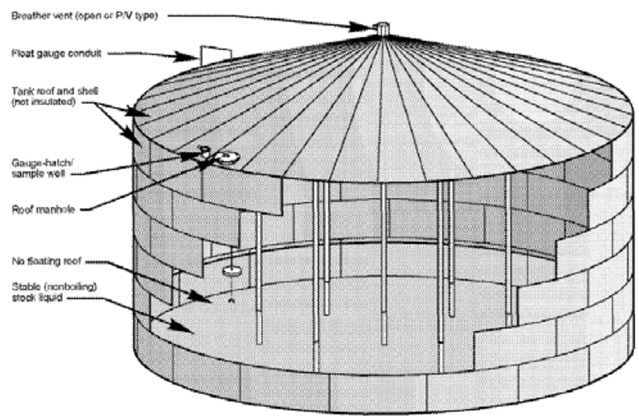

Figure 1. Typical Fixed Roof Tank

The equations below assume the following (for instances where the assumptions below are not valid refer to API MPMS 19.1):

- Vertical tanks
- Liquid with a true vapor pressure less than or equal to 0.1 psia (equivalent to 70 API gravity crude)

The **standing losses** from a fixed roof storage tank can be estimated using the equation below. For more information on the dimensionless factors used in the equation below refer to the API MPMS Chapter 19.1.

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

where,

L_S = total standing losses (lb/yr)
K_E = vapor space expansion factor (dimensionless)
H_{VO} = height of vapor space between tank roof and liquid surface (ft)
D = tank diameter (ft)
K_s = vented vapor saturation factor (dimensionless)
W_V = stock vapor density (lb/ft^3)

The **working losses** from a fixed roof storage tank can be estimated using the equation below. For more information on the dimensionless factors used in the equation below refer to the API MPMS Chapter 19.1.

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

where,

L_W = total standing losses (lb/yr)
N = stock turnover rate (turnover/yr)
H_{LX} = stock maximum liquid height (ft)
D = tank diameter (ft)
K_N = working loss turnover factor (dimensionless)
K_P = working loss product factor (dimensionless)

K_B = venting setting correction factor (dimensionless) = 1; unless $K_N \left[\frac{P_{BP}+P_A}{P_{VI}+P_A}\right] > 1.0$

$$K_B = \left[\frac{\frac{P_{VI}+P_A}{K_N} - P_{VA}}{P_{BP}+P_A-P_{VA}}\right]$$

P_{BP} = breather vent pressure setting (psig)
P_A = atmospheric pressure (psia)
P_{VI} = pressure of the vapor space at normal operation conditions (psig)
P_{VA} = stock vapor pressure at the daily average liquid surface temperature (psig)

W_V = stock vapor density (lb/ft^3)

Floating Roof

A floating roof tank has a raft like deck that floats on the liquid surface. A small space around the perimeter of the floating roof allows the deck to rise and fall as the tank is filled and emptied. This space is sealed by a flexible rim seal preventing vapors from escaping.

However, the floating roof rim seal can be a large source of emissions from floating roof tanks. There are various types of seals from wiper seals, shoe seals, and envelope seals. There are also primary seals (only one seal used) and secondary seals (tandem seals). When there is a secondary seal, the primary seal is mounted below the secondary seal. The primary seal is closest to the liquid and the upper seal is the secondary.

The floating roof reduces evaporative losses by reducing the vapor head space in the tank practically eliminating working losses. The total evaporation loss for floating roof tanks is equal to the standing loss plus the withdrawal loss. Working losses in floating tanks are negligible because the floating roof does not allow the accumulation of vapors between the liquid level and the shell roof. This prevents rising and falling liquid levels from changing the pressure of the vapors in the tank. Withdrawal loss is the evaporation from residual liquid that clings to the tank shell and any support columns while the tank is being emptied. In most cases this is negligible when compared to the standing storage loss thus little emphasis is placed on this type of loss.

There are three types of floating roof tanks:

IFRT (Internal Floating Roof Tanks) - covered by a fixed roof on top of the shell with a light floating roof (Figure 2.) The IFRT's have sources of emissions from the floating roof deck, floating roof rim seal, and the floating roof bolts. Major emissions also occur from the slotted gauge poles, roof legs, and column legs.

IFRT's use either:

- **Welded** roof decks, where all seams are welded together (most common – designed to be liquid and vapor tight)
- **Bolted** **contact** roof decks where the seams are bolted and the roof comes in contact with the liquid
- **Bolted** **non-contact** roof decks where the roof does not come in contact with liquid.

CFRT (Covered Floating Roof Tank) - covered by a fixed roof on top of the shell with a heavier floating roof (Figure 3.) CFRT's use welded roofs eliminating emission through the roof, but the tank seals and roof fittings are still sources of emissions. CFRT's also have major emissions from the slotted gauge poles, roof legs, and column legs.

EFRT (External Floating Roof Tanks) - exposed to atmosphere with a heavier floating roof (Figure 4.) EFRT's use welded roofs, thus no emissions occur through the floating roof, but the tank seals and roof fittings are still sources of emissions. Like IFRT's and CFRT's, EFRT's also have major emission from the slotted gauge poles, roof legs, and column legs.

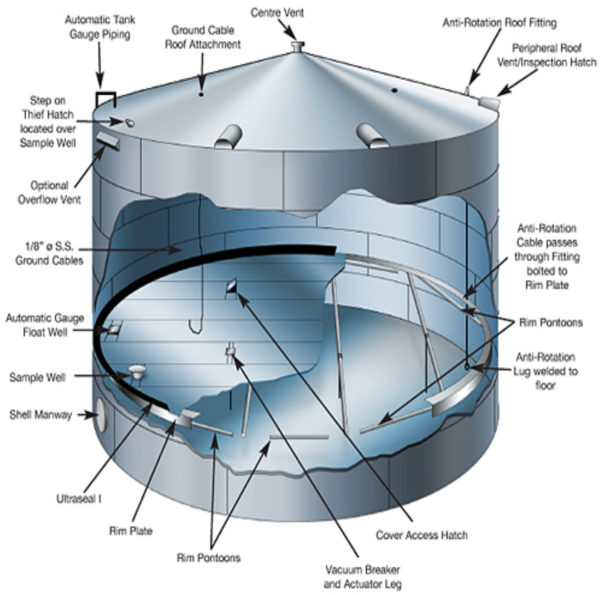

Figure 2. Internal Floating Roof Tank

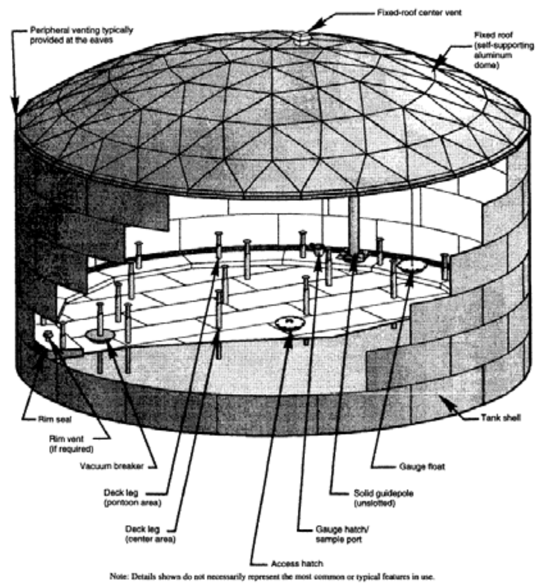

Figure 3. Covered Floating Roof Tank

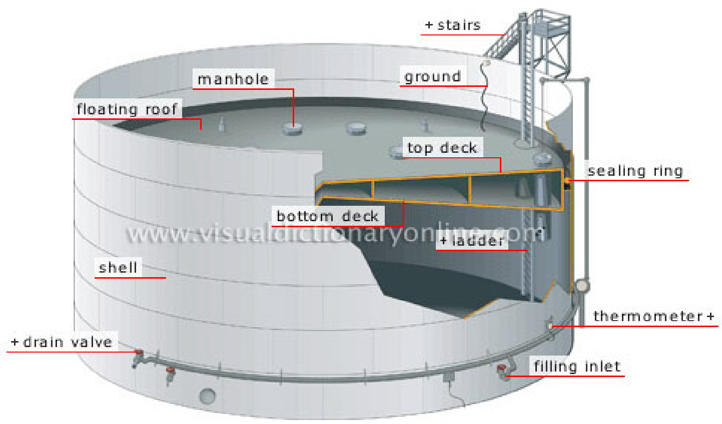

Figure 4. External Floating Roof Tank

The API equations below assume the following (for instances where the assumptions below are not valid refer to API MPMS 19.2):

- True vapor pressure 0.1-14.7 psia
- Average wind speeds 0-15 mph
- Tank diameters greater than 20 feet

Standing losses is the evaporation past the floating roof during normal conditions and can be calculated using the equation below. The equation accounts for standing losses from the rim seals, deck fittings, and deck seams (if bolted). For more information on the variables used in the equation below refer to the API MPMS Chapter 19.2.

$$L_S = \left[(F_r) + (F_f) + (F_d)\right] P^* \, M_v \, K_c$$

where,

L_S	=	total standing losses (lb/yr)
F_r	=	total rim-seal loss factor (lb-moles/yr)
F_f	=	total deck-fitting loss factor (lb-mole/yr)
F_d	=	total deck-seam loss factor (lb-mole/yr)
P^*	=	vapor pressure function (dimensionless)

M_v = average molecular weight of stock vapor (lb/lb-mole)
K_c = product factor (dimensionless)

Withdrawal losses come from liquid that clings to the tank shell and support columns when the tank is being emptied. In most cases this is negligible when compared to standing losses, thus little emphasis is placed on this type of loss. The equation below can be used to calculate withdrawal losses. For more information on the variables used in the equation below refer to the API MPMS Chapter 19.2.

$$L_W = \left[\frac{(0.943)\ QCW_l}{D}\right]\left[1 + \frac{N_{fc}\ F_c}{D}\right]$$

where,

L_W = total withdrawal losses (lb/yr)
Q = annual net flow rate through the tank (bbl/yr)
C = clingage factor (bbl/1000 ft^2)
W_l = average liquid stock density at the average storage temperature (lb/gal)
D = tank diameter (ft)
N_{fc} = number of fixed-roof support columns (dimensionless)
F_c = effective column diameter (ft)

Software

There are also several software packages available that calculate evaporative losses from storage tanks. *TANKS* is a free program developed by the EPA that estimates VOC and hazardous air pollutant emissions from fixed- and floating- roof storage tanks.[2] *TANKS* is based on the calculation methodology in the API MPMS, Chapter 19; the same as those summarized above. *HYSYS* and *PROMAX* are process simulators that calculate flashing and evaporative losses from storage tanks using the calculation methodology in the API MPMS, Chapter 19; also the same as those summarized above. Care must be taken when using software since software packages may include default assumptions in the emission calculations that may not accurately represent the tank being characterized.

REDUCTION METHODS

With new regulations such as EPA's New Source Performance Standard (NSPS) Subpart OOOO, being proactive about reducing tank emissions is paramount. NSPS Subpart OOOO[3] for the oil and gas industry requires a 95% reduction in volatile organic compound (VOC) emissions from storage tanks emitting at least 6 tons per year of VOCs. Operators may be able to avoid having some tanks fall subject to NSPS OOOO by implementing the reduction methods discussed below. In addition, reducing evaporative losses will add otherwise lost product back to a company's balance sheet as revenue.

Tank Paint Condition and Color

The appropriate condition and color of the tank's shell and roof can significantly reduce evaporation losses. Since evaporative losses are proportional to the temperature of the stored liquid, reducing the temperature of the stored liquid can reduce evaporative losses. Solar radiation will heat the liquid in a storage tank, but the extent of heating is determined by the color and condition of the paint on the tank walls and roof. Paints with a low solar absorptance (i.e., high reflectance) will heat up less than paints with high solar absorptance. Subsequently, the liquid in a storage tank with low-solar-absorptance paint will maintain lower temperatures and lower evaporative losses. White paint is highly reflective and commonly used to lower the tank shell temperature thus reducing standing losses. Figure 5 below is from API MPMS Chapter 19 Section 1 and shows a comparison of various paint colors' solar absorptance.

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[2] U.S. Environmental Protection Agency. *TANKS Emission Estimation Software,* Version 4.09D. <www.epa.gov/ttnchie1/software/tanks/>

[3] U.S. Environmental Protection Agency. *Oil and Natural Gas Sector: New Source Performance Standards; Final Rule.* 40 CFR Part 60. Subpart OOOO. <www.gpo.gov/fdsys/pkg/FR-2012-08-16/pdf/2012-16806.pdf>

		Solar Absorptance (α) (dimensionless) Surface Condition	
Surface Color	Shade or Type	Good	Poor
Aluminum	Specular	0.39	0.49
Aluminum	Diffuse	0.60	0.68
Beige/Cream		0.35	0.49
Brown		0.58	0.67
Gray	Light	0.54	0.63
Gray	Medium	0.68	0.74
Green	Dark	0.89	0.91
Red	Primer	0.89	0.91
Rust	Red iron oxide	0.38	0.50
Tan		0.43	0.55
White	—	0.17	0.34
Aluminum	Mill finish, unpainted	0.10	0.15

Figure 5. Solar Absorptance for Selected Tank Surfaces

Preventative Maintenance

Tank vapors are released to the atmosphere via the tank vent, thief hatch, and leakage. These three emission mechanisms can be prevented or at least reduced through good preventative maintenance practices. Tank vents are purposely designed to vent tank vapors to avoid unsafe pressure in the tank. Thief hatches are opened, releasing tank vapors, to manually gauge or sample the tank liquids. And leaks randomly occur when valves, gaskets, flanges, and connections on tanks malfunction and allow tank vapors to pass to the atmosphere. Thief hatch releases can be minimized by reducing the time the hatch is open or by using external gauges. Thief hatch seal leaks are a common source of tank emissions. Premium hatches are available to provide a better seal, but frequently surveying tank seals and relief valves is the best method to reduce emissions from leaks. Optical gas imaging cameras are designed to “see” hydrocarbon leaks (because the naked-eye cannot) and are a powerful tool to identify leaking thief hatches and tank vents.

Vapor Recovery Units and Combustion Systems

The vapor from tanks at a well site can be routed to a combustion device or a vapor recovery unit. The vapor space in several tanks is connected via a large diameter pipe (e.g. 4” I.D.) and routed to a small compressor unit where the gas is compressed and sent to sales or routed as fuel. Figure 6 below is an example of three tanks connected to a vapor recovery unit. The same routing system can also be used to direct tank vapors to a combustion device (e.g. flare). These routing systems are especially common at natural gas well sites with strict air permit requirements. Vapor recovery and combustion systems are installed primarily to mitigate flashing losses from tanks, however, evaporative losses are also reduced with their installation. When designing tank vapor recovery and combustion systems, the appropriate balance must be established between the set points on the tank vents and the minimum tank pressure necessary for the vapor recovery compressor to run. Maintaining this balance is essential to ensuring the successful operation of any vapor recovery system. Operators must frequently inspect combustion devices to ensure the complete burn of tank vapors. In windy or cold conditions, the pilot light on a combustion device can go out resulting in a steady flow of tank vapors to the atmosphere.

Figure 6. Vapor Recovery System

CONCLUSION

It is important to be familiar with the potential sources of evaporative loss on crude oil and condensate storage tanks and take the necessary steps to help reduce these losses. The equations in this paper provide a starting point for understanding the variables that impact evaporative losses. These equations can be applied to individual tanks to gain a better understanding of the environmental and bottom line impact companywide. One must keep in mind, however, that the largest source of storage tank losses occurs due to flashing not due to evaporation. Vapor recovery units and combustors are the best solution to mitigate flashing and evaporative losses from storage tanks simultaneously. Also, companies are inclined to paint their storage tanks with their corporate logos and colors, which may result in air permitting implications and greater storage tank losses. Limiting non-white paint colors on tanks and implementing a proactive preventative maintenance program for tanks will significantly reduce evaporative losses from crude and condensate storage tanks.

REFERENCES

American Petroleum Institute, “Evaporative Loss From Fixed Roof Tanks,” Manual of Petroleum Measurement Standards, Chapter 19.1, Washington, D.C., First Edition, 1991.

American Petroleum Institute, “Evaporative Loss From Floating-Roof Tanks,” Manual of Petroleum Measurement Standards, Chapter 19.2, Washington, D.C., First Edition, April 1997.

HY-BON. *Vapor Recovery Unit (VRU).* Image. Access on 24 Jan 2014 at <hy-bon.com/products/vru/>

Sage Energy. *Vapor Recovery Units (50 HP+)*. Image. Accessed on 20 Jan. 2014 at <sageenergy.ca/products/vapor-recovery-systems/>

United States Environmental Protection Agency. “7.1 Organic Liquids Storage Tanks,” *AP 42*, *Fifth Edition, Volume I, Chapter 7: Liquid Storage Tanks.* <www.epa.gov/ttn/chief/ap42/ch07/index.html>