

Air Resources Board's Draft Approach to Estimating Aboveground Storage Tank Emission Factors using the AP-42 Method

Introduction

The California Air Resources Board (ARB) is currently developing a statewide emission inventory of Aboveground Storage Tanks (AST) as part of its Enhanced Vapor Recovery Rulemaking. ARB staff intends to use the equations in AP-42, developed by the American Petroleum Institute, to determine AST emission factors from single-wall and protected ASTs. The statewide AST emission inventory will be based on these emission factors.

AP-42, a document published by the U.S. Environmental Protection Agency (EPA), consists of a detailed method for calculating emissions losses from single-wall storage tanks. AP-42 can be viewed under section "Organic Liquid Storage Tanks" (Background Document) on the U.S EPA's website at <http://www.epa.gov/ttn/chief/ap42/ch07/index.html>. To use AP-42 for protected tanks, fuel surface temperatures are required. Since August of this year, ARB staff has monitored several protected ASTs of various sizes (see the November 3, 2004 presentation on the AST vapor recovery website at <http://www.arb.ca.gov/vapor/ast/ast.htm> for more information). The purpose for monitoring these tanks was to acquire the fuel surface temperature information needed for the AP-42 equations.

This document presents the stepwise approach of calculating emission factors for single-wall (Non-Insulated) and protected (Insulated) ASTs using AP-42. Some equations used in AP-42 have been modified based on the AST configurations being evaluated. Assumptions are listed along with their respective equation. Appendix A contains an example of emission factor estimates for a Non-Insulated and Insulated AST located in Sacramento.

Total Losses from Storage Tanks

The following equations apply to horizontal aboveground storage tanks (ASTs) that store organic liquids i.e. gasoline. These tanks must be substantially liquid and vapor-tight and must operate at atmospheric pressure. Total losses from ASTs are equal to the sum of the standing storage loss and working loss calculated for each month:

$$L_T = L_S + L_W$$

Where:

L_T = total losses, lb/month

L_S = standing storage loss, lb/month

L_W = working loss, lb/month

Standing Storage or Breathing Loss

$$L_S = nV_vW_vK_EK_S$$

Where:

- L_S = Standing storage losses, lb/month
- n = number of days in the respective month
- V_v = vapor space volume of the ullage, ft³
- W_v = vapor density, lb/ft³
- K_E = vapor space expansion factor, dimensionless
- K_S = vented vapor saturation factor, dimensionless

- ◆ **Tank vapor space volume, V_v** , is considered to be equal to the ullage volume and is estimated as:

Assumption: The ASTs being considered in this evaluation are horizontal with no roof outage or vapor space outage factor. The AST is half-full so therefore V_v is half the AST capacity. When a range of tank capacities are considered, the average tank capacity is used and divided by 7.481 to convert gallons into ft³. The following equation is a modified version of the AP-42 equation.

$$V_v = \frac{1}{2} \text{ tank capacity (ft}^3\text{)}$$

Example: Tank capacity range = 751-1000 gallons
Average tank capacity = 875.5 gallons = $875.5/7.481 = 117 \text{ ft}^3$
 $V_v = 1/2 * 117 = 58.5 \text{ ft}^3$

- ◆ **Vapor Density, W_v** , is the density of the vapor and is calculated using the following equation:

$$W_v = M_v P_{VA} / RT_{LA}$$

Where:

- W_v = vapor density, lb/ft³
- M_v = vapor molecular weight, lb/lb-mole
- R = the ideal gas constant, 10.731 psia·ft³/lb-mole·°R
- P_{VA} = vapor pressure at daily average liquid-surface temperature, psia
- T_{LA} = daily average liquid (gasoline) surface temperature, °R

- **Molecular weight of the vapor (M_v)** is obtained from the Table 3-2 in AP-42, listing the physical properties of gasoline. The molecular weight of gasoline changes with the change in Reid Vapor Pressure (RVP).

Assumption: The RVP of gasoline for the summer months (April to October) is 7.0 psi and for the winter months (November to March) is 9.0 psi.

Listed below are the molecular weight of gasoline for each corresponding RVP:

April-October – RVP = 7 psi, $M_v = 68$
November-March – RVP = 9 psi, $M_v = 67$

- **True vapor pressure (P_{VA})** of gasoline stocks, at the daily average liquid surface temperature, can be determined using the following equation:

$$P_{VA} = \exp [A - (B/T_{LA})]$$

Where:

exp = exponential function

T_{LA} = daily average liquid (gasoline) surface temperature, °R

Figure 3-5 in AP-42 shows the equations used to determine vapor pressure constants, A (dimensionless) and B (°R) for each corresponding RVP of gasoline:

RVP = 7 psi, A = 11.83 and B = 5500.90, °R

RVP = 9 psi, A = 11.75 and B = 5314.31, °R

- **Daily average liquid (gasoline) surface temperature (T_{LA})** is calculated using the following equation:

$$T_{LA} = (T_{LN} + T_{LX})/2$$

Where:

T_{LN} = daily minimum liquid (gasoline) surface temperature, °R

T_{LX} = daily maximum liquid (gasoline) surface temperature, °R

These values are determined from ambient temperature data obtained from AP-42 "TANKS" software. This software has ambient temperature data in (°F) for sixteen cities in California. Using this data, the following can be determined for ASTs within each of the sixteen cities:

$T_{amb.avg}$ = daily ambient average temperature, °F

$T_{amb.range}$ = daily ambient temperature range, °F or °R

Study conducted to determine the effect of daily ambient temperatures on gasoline surface temperatures (T_{LN} and T_{LX}):

ARB staff conducted a four-month study to measure ambient temperatures and gasoline surface temperatures for single wall (non-insulated) and protected (insulated) ASTs. Although all of the data has not been analyzed, the following correlations between ambient and gasoline surface temperatures are preliminary estimates.

Single Wall (Non-Insulated) ASTs:

Gasoline surface temperature range = Ambient temperature range attenuated by factor 0.17

The study indicated that the diurnal changes in ambient temperature have a similar diurnal effect on the gasoline surface temperature as shown in Figure 1.

Protected (Insulated) ASTs:

Gasoline surface temperature range = Ambient temperature range attenuated by factor 0.80

The study indicated that diurnal changes in ambient temperature have a very small effect on the gasoline surface temperature as shown in Figure 2.

Using the above attenuation factors and ambient temperature data, the daily minimum and maximum liquid (gasoline) surface temperatures can be estimated for both

non-insulated and insulated ASTs as follows: Please note that amb.avg temperature is converted from °F to °R by adding 460.

The daily minimum liquid (gasoline) surface temperature (T_{LN}) can be calculated as:

$$T_{LN} = [T_{amb.avg} + 460] - [(1 - \text{Attenuation factor}) * (T_{ambrange} / 2)]$$

The daily maximum liquid (gasoline) surface temperature (T_{LX}) can be calculated as:

$$T_{LX} = [T_{amb.avg} + 460] + [(1 - \text{Attenuation factor}) * (T_{ambrange} / 2)]$$

- ◆ **Vapor Space Expansion Factor, K_E** - the vapor space expansion factor is calculated using the following equation:

$$K_E = [(\Delta T_V / T_{LA})] + [(\Delta P_V - P_B) / (14.7 - P_{VA})]$$

Where:

K_E = dimensionless factor

ΔT_V = daily vapor temperature range, °R

ΔP_V = daily vapor pressure range, psi

P_B = breather vent pressure setting range, psi

14.7 = atmospheric pressure, psi

P_{VA} = vapor pressure at daily average liquid surface temperature, psi (derived earlier)

T_{LA} = daily average liquid (gasoline) surface temperature, °R (derived earlier)

- **The daily vapor temperature range, ΔT_V ,** is calculated below using the daily maximum and daily minimum liquid (gasoline) surface temperatures (derived earlier):

Assumption: The vapor temperature range is equal to the liquid (gasoline) surface temperature range.

$$\Delta T_V = T_{LX} - T_{LN}$$

- **The daily vapor pressure range, ΔP_V ,** is calculated using the following equation:

$$\Delta P_V = P_{VX} - P_{VN}$$

Where:

P_{VX} = vapor pressure P_{VA} at daily maximum liquid (gasoline) surface temperature, psi

P_{VN} = vapor pressure P_{VA} at daily minimum liquid (gasoline) surface temperature, psi

Using the daily maximum and daily minimum liquid (gasoline) surface temperatures, the respective vapor pressures can be calculated as:

$$P_{VX} = \exp[A - (B / T_{LX})]$$

$$P_{VN} = \exp[A - (B / T_{LN})]$$

Where:

RVP = 7 psi, A = 11.83 and B = 5500.90 °R

RVP = 9 psi, A = 11.75 and B = 5314.31 °R

- **The breather vent pressure setting range, delta P_B**, is calculated using the following equation:

$$? P_B = P_{BP} - P_{BV}$$

Where:

?P_B = breather vent range (psi)

P_{BP} = breather vent pressure setting (psi)

P_{BV} = breather vent vacuum setting (psi)

For ASTs with a pressure/vacuum vent valve

P_{BP} = 2 inH₂O ≅ 0.0722 psi

P_{BV} = -4 inH₂O ≅ - 0.1444 psi

For ASTs with no pressure/vacuum vent valve

P_{BP} = 0 inH₂O ≅ 0 psi

P_{BV} = 0 inH₂O ≅ 0 psi

- **The vapor pressure at daily average liquid (gasoline) surface temperature, P_{VA}**, is calculated as shown earlier.
- **The daily average liquid (gasoline) surface temperature, T_{LA}**, is calculated as shown earlier.

- ◆ **Vented Vapor Saturation Factor, K_S** – The vented vapor saturation factor is calculated using the following equation:

$$K_s = \frac{1}{1+(0.053 \cdot P_{VA} \cdot H_{VO})} = 1$$

Where:

K_s = dimensionless factor

P_{VA} = vapor pressure at daily average fuel surface temperature, psi

H_{VO} = vapor space outage = 0 ft

(As mentioned earlier, the ASTs being considered in this evaluation are horizontal with no roof outage or vapor space outage factor)

Working Loss

Working loss is the mass of vapors emitted during the:

- transfer of gasoline from the cargo tank to the AST (Deliveries); and
- transfer of gasoline from the AST to the vehicle (Dispenses).

The general equation for working loss is as follows:

$$L_w = L_w (\text{Deliveries}) + L_w (\text{Dispenses})$$

Where:

L_w = total working loss, lb/month

$L_w (\text{Deliveries})$ = working loss due to deliveries made into an AST, lb/month

$L_w (\text{Dispenses})$ = working loss due to dispenses from an AST into vehicle tank, lb/month

Working loss can be minimized by controlling displaced vapors during gasoline deliveries into AST (Phase I) or during gasoline dispenses into a vehicle (Phase II). In California, the air quality districts regulate whether or not an AST is required to have Phase I and/or Phase II controls. Therefore, the AST may have no vapor recovery controls, Phase I vapor recovery control only, or both Phase I and Phase II vapor recovery controls. The total working loss will be different for each of the three configurations.

Assumptions The AST is 80% empty when the cargo tank delivers gasoline into it. The number of deliveries per year is 2. The volume of gasoline delivered to the AST is equal to the volume of gasoline dispensed from the AST into vehicle tanks. The volume of gasoline delivered to the AST is calculated as follows:

$$V_{(\text{Delivered})} = N_{(\text{Deliveries})} * (\text{AST Capacity} * 0.80)$$

Where:

$V_{(\text{Delivered})}$ = volume of the gasoline delivered to AST

$N_{(\text{Deliveries})}$ = number of deliveries made per year to AST

AST capacity, ft³ (derived earlier)

◆ **No Vapor Recovery Control, Phase I = 0, Phase II = 0**

For no Phase I and Phase II vapor recovery control, the volume of vapors displaced during a delivery and dispensing is equal to the volume of gasoline delivered to the AST and dispensed to a vehicle tank respectively. All the vapors displaced during the delivery and dispensing are lost to the atmosphere. The working loss due to dispenses is equal to the working loss due to deliveries.

$$L_w (\text{Deliveries}) = (V_{(\text{Delivered})} * W_v) / 12$$

$$L_w (\text{Dispenses}) = (V_{(\text{Delivered})} * W_v) / 12$$

Where:

W_v = vapor density, lb/ft³ (derived earlier)

12 = number of months in a year

◆ **Phase I Vapor Recovery Control, Phase I = 0.95, Phase II = 0**

For Phase I vapor recovery control, 95% of the volume of vapors displaced during a delivery is returned to the cargo tank. The remaining 5% is lost to the atmosphere. Due to no Phase II control, volume of vapors displaced during a dispense is equal to the volume of gasoline dispensed to the vehicle. Therefore, all the vapors displaced during a dispense are lost to the atmosphere.

$$LW_{\text{ (Deliveries)}} = [V_{\text{ (Delivered)}} * W_V] / 12 (1 - 0.95)$$

$$LW_{\text{ (Dispenses)}} = (V_{\text{ (Delivered)}} * W_V) / 12$$

◆ **Phase I and Phase II Vapor Recovery Control, Phase I = 0.95, Phase II = 0.95**

For Phase I and Phase II vapor recovery control, 95% of the volume of vapors displaced during a delivery and dispensing are returned to the cargo tank and AST respectively. The remaining 5% are lost to the atmosphere.

$$LW_{\text{ (Deliveries)}} = (V_{\text{ (Delivered)}} * W_V) / 12 * [1 - 0.95]$$

$$LW_{\text{ (Dispenses)}} = (V_{\text{ (Delivered)}} * W_V) / 12 * [1 - 0.95]$$

Conclusion

The above described, AP-42 method of calculating emission factors for aboveground storage tanks (ASTs) accounts for two significant factors:

Seasonal Variation – The example used in Appendix A, indicates that emissions from tanks are higher during summer months than during winter months. This is as expected because temperatures are higher and have a greater range in the summer months.

Tank Characteristics – An insulated (protected) tank generates lower emissions than a non-insulated (single wall) tank. The example in Appendix A, clearly shows that influence of diurnal swings in ambient temperature have less effect on gasoline surface temperature in an insulated tank vs. a non-insulated tank. Therefore, the gasoline surface temperature remains very stable in an insulated tank, causing lower emissions.

ARB staff intends to apply this approach to various categories of ASTs by size, type, vapor recovery configuration, and location for determining the various emission factors. An inventory is currently being developed to determine the different types and population of ASTs used in California. Further modifications or refinements to this approach may be needed based on new information or comments received from the Stakeholder Review Team.

Figure 1- Ambient Temperature Compared to Gasoline Surface Temperature in a Single-Wall (Non-Insulated) Tank

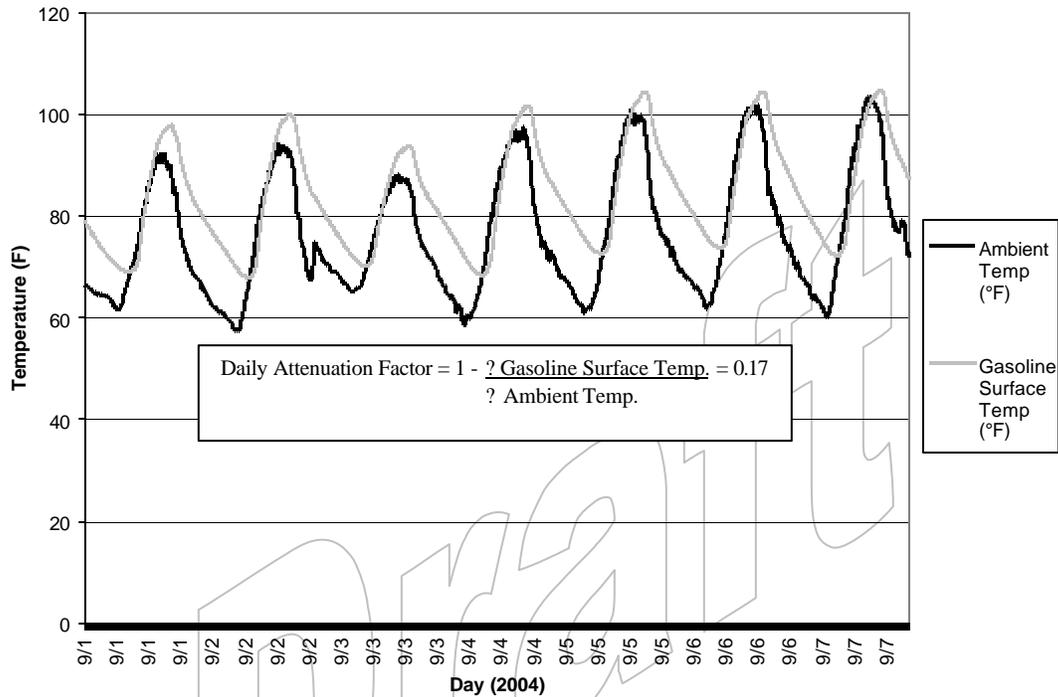
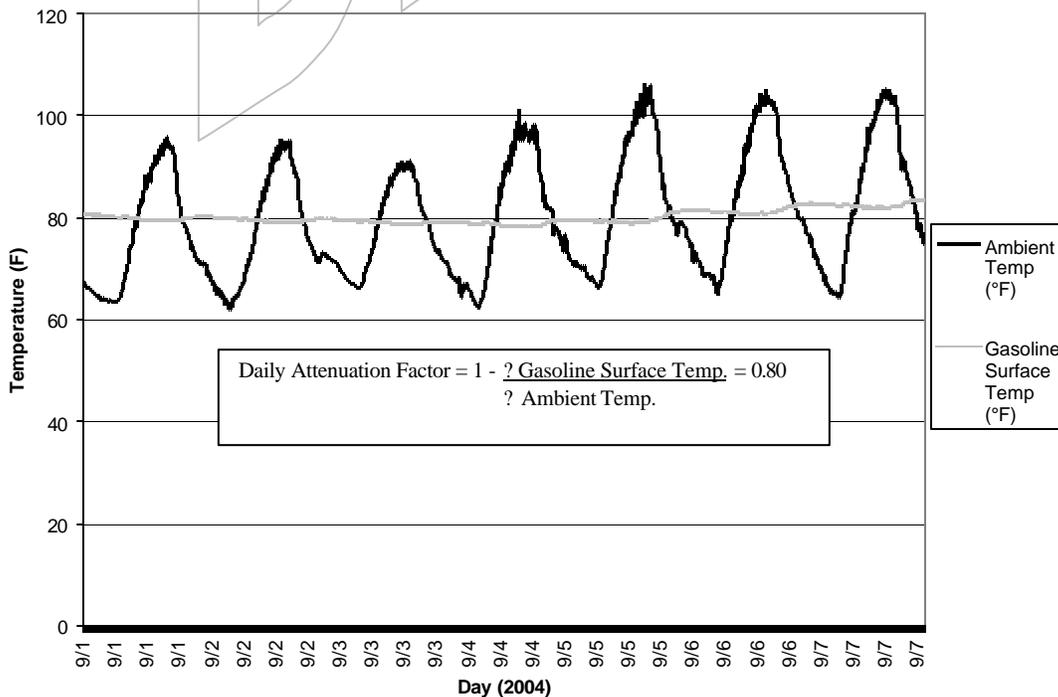


Figure 2- Ambient Temperature Compared to Gasoline Surface Temperature in a Protected (Insulated) Tank



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APPENDIX A