Evaporative Loss from Closed-vent Internal Floating-roof Storage Tanks

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Measurement Coordination Department

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0. SUMMARY

There is presently no recognized methodology for estimating the impact of closed tank vents on emissions from an internal floating-roof tank (IFRT). When the vents in the fixed roof of an IFRT are closed, rather than open, estimation of emissions is shown to be highly complex.

Emissions reductions from adding closed vents to IFRTs were found to be significant only for small diameter tanks storing volatile liquids with infrequent turnovers. For low volatility stocks such as diesel, the emission reductions due to adding closed vents are generally less than 10% regardless of the tank diameter or frequency of turnovers. For IFRTs 60 ft in diameter and larger, experiencing 18 or more turnovers per year, the emission reductions due to adding closed vents are generally less than 10%, regardless of the liquid stored or the vent settings on the tank (assuming that the pressure setting is not so high as to require the tank to be anchored).

Given the high uncertainty associated with the methods evaluated, an assumption of a 5% reduction in emissions from an IFRT due to use of closed vents would be a reasonable approach for emissions estimating.

1. INTRODUCTION

This report addresses evaporative loss from internal floating-roof tanks (IFRTs) with closed vents, a subject not currently addressed by API. Nomenclature is provided in Appendix A.

The API *Manual of Petroleum Measurement Standards* Chapter 19, Section 1 (19.1)[1] addresses evaporative loss from fixed-roof tanks, and specifically excludes fixed-roof tanks that have an internal floating roof (19.1.1.1).

The API *Manual of Petroleum Measurement Standards* Chapter 19, Section 2 (19.2)[2] addresses evaporative loss from freely-vented internal floating-roof tanks, and specifically excludes "closed internal floating-roof tanks (that is, tanks vented only through a pressure-vacuum relief vent, blanketed with an inert gas, vented to a vapor processing unit, or otherwise restricted from being freely vented)" (1d).

2. CLOSED-VENT INTERNAL FLOATING-ROOF STORAGE TANKS

2.1 Venting

API 650, *Welded Steel Tanks for Oil Storage*[3], H.5.2.2 addresses venting for internal floating-roof tanks. Two options are allowed: open circulation vents or closed pressure-vacuum vents. For closed pressure-vacuum vents, gas blanketing or another method to prevent the development of a combustible gas mixture within the tank is required.

2.2 Vacuum

Until the December 2005 Addendum, API 650 limited the design vacuum to 1 in. water column, which is 0.036 psi (API 650, 5.2.1b). (API 650 now allows up to 1.0 psi design vacuum, but the vast majority of existing storage tanks are not designed to withstand more than 0.036 psi vacuum.)

2.3 Pressure

API 650 limits the design pressure for tanks to 2.5 psi (API 650, 5.2.1c). Cone-roof tanks with pressure exceeding about 0.053 psi (the weight per unit area of typical $^{3}/_{16}$ in. thick roof plates) require special design (Appendix F), and anchoring the tank is required if the pressure exceeds the weight of the roof and the shell divided by the tank's cross-sectional area. Also, if the design pressure exceeds a certain threshold, the shell-to-roof joint required to resist the pressure becomes too large to be considered frangible (i.e. a weak roof-to-shell joint as specified in API 650, 5.10.2.6), and the tank requires emergency vents. These pressure thresholds are shown in the API 650 Tank Design Pressures Table for 48 ft tall cone-roof tanks. Shell thicknesses are taken as the greatest of those required for the stored liquid (0.7 specific gravity), the hydrotest, and minimum thicknesses allowed in API 650. (Tanks are often designed with thicker shells in order to avoid the need for an intermediate wind girder. A thicker tank shell would increase the maximum pressures shown below.)

API 650 Tank Design Pressures

Tank Diameter (ft)	Maximum Pressure with Frangible Joint (psi)	Maximum Pressure without Anchors (psi)
48	0.199	0.285
60	0.205	0.294
90	0.178	0.251
120	0.175	0.247
150	0.169	0.238

The internal floating roof must also be capable of withstanding the internal pressure. API 650 describes several different types of floating roofs in H.2.2, including internal floating roofs that have their deck above the liquid and are supported by closed pontoons for buoyancy (H.2.2.e). These pontoons are typically 10 in. diameter, 0.050 in. thick aluminum and cannot withstand pressures above about 0.07 psi (unless special fabrication measures are taken to pressurize the pontoons).

2.4 European Practice

In Europe, pressure-vacuum vents are commonly used without gas blanketing the vapor space above the floating roof. The German standard DIN 4119 specifies that new tanks must be designed for a 0.29 psi relieving pressure (20 mbar) and a 0.145 psi (10 mbar) relieving vacuum[6]. The German design pressure is approximately the maximum pressure tanks can withstand without anchors.

3. EMISSION REDUCTIONS FROM FLOATING ROOFS VS EMISSION REDUCTIONS FROM CLOSED VENTS

Both internal floating roofs and closed vents reduce emissions from storage tanks. Let's first quantify the reduction each of these controls achieves separately before considering their combined effect.

3.1 Emission Reductions from Internal Floating Roofs

First, consider the emission reduction achieved by adding an internal floating roof to a tank with open vents. Consider tanks 48 ft tall storing RVP 10 gasoline or diesel at 14.5 psi atmospheric pressure, 60^{o}F average liquid surface temperature, 20^{o}F daily temperature range, and 25 turnovers per year. Their internal floating roof is welded steel with a vapor mounted primary and rim mounted secondary seal.

The evaporative loss without the floating roof is determined using API *MPMS* Ch. 19.1 with zero vent pressure/vacuum settings. The evaporative loss with the floating roof is determined using API *MPMS* Ch. 19.2.

Table 1—Evaporative Loss (lb/yr) for Open-vent Tanks with and without an Internal Floating Roof

	DIESEL			GASOLINE (RVP 10)		
Tank Diameter *D* (ft)	Loss without a Floating Roof $L_{T19.1}$	Loss with a Floating Roof $L_{T19.2}$	% Reduction	Loss without a Floating Roof $L_{T19.1}$	Loss with a Floating Roof $L_{T19.2}$	% Reduction
30	139	7	95.0%	51,154	1,567	96.9%
60	558	12	97.8%	204,614	2,410	98.8%
90	1,255	20	98.4%	460,382	4,168	99.1%
120	2,231	27	98.8%	818,457	5,481	99.3%

For the cases shown in the table above, adding a floating roof to an open-vent tank reduces emissions by approximately 95% to 99%, a fairly substantial reduction.

3.2 Emission Reductions from Closed Vents

Next, consider the emission reduction achieved by adding closed vents to a tank without a floating roof. The tank has the same parameters as in 3.1 above, except that only RVP 10 gasoline is stored, and the pressure/vacuum settings are as given in Table 2. The P/V settings range from the lowest to the highest usually encountered in unanchored storage tanks.

The lowest non-zero range used in the example is for +/– 1 in. of water column (+/– 0.036 psi), which is slightly greater than the typical breather vent setting of +/– ½ oz/in.^{2} (+/– 0.031 psi). The pressure for the highest range is based on the approximate weight of the tank roof and shell, which is the limit above which anchorage is required. This is equivalent to approximately 0.3 psi for a 48-ft diameter tank and less for larger tanks. The API 650 tank design standard[3] has historically limited the design vacuum to 1 in. water column (–0.036 psi) as noted in Section 2 above. This limitation has been removed in the most recent 650 edition, however, so larger vacuum settings are considered in this investigation. For the cases in which the pressure is greater than the minimum case, the vacuum setting is arbitrarily taken as one half of the pressure setting.

The Table 1 loss without a floating roof is the same as the Table 2 loss for a P/V setting of zero, since these are for the same case: an open-vent fixed-roof tank without an internal floating roof.

Table 2—Evaporative Loss (lb/yr) for Fixed-roof Tanks with Various Pressure/Vacuum Settings

Tank Diameter D (ft)	GASOLINE (RVP 10)								
	P/V +0 –0	P/V +0.036 –0.036	% Red.	P/V 0.100 –0.050	% Red.	P/V 0.200 –0.100	% Red.	P/V 0.300 –0.150	% Red.
30	51,154	50,617	1.0%	50,037	2.2%	48,928	4.4%	47,826	6.5%
60	204,614	202,467		200,150		195,713		191,305	
90	460,382	455,550		450,337		440,355		430,436	
120	818,457	809,867		800,598		782,854		765,219	

For the cases shown in the table above, adding closed vents to a tank without an internal floating roof reduces emissions by 1% to 6%. This is much less than the 95% to 99% emission reduction that results from adding an internal floating roof to a tank with open vents. Even relatively high vent settings do not reduce emissions by more than about 6% compared to open-vent tanks.

Therefore, closed-vent internal floating-roof tanks are not expected to have significantly less emissions than open-vent internal floating-roof tanks. Said another way, emissions from closed-vent IFRTs will be much closer to emissions from open-vent IFRTs than to emissions from closed-vent tanks without internal floating roofs.

4. THE ITERATIVE METHOD FOR ESTIMATING EMISSIONS FOR CLOSED-VENT IFRTs

To better understand closed-vent IFRT emissions, we constructed the model described below to determine the daily vapor content of the vapor space above the floating roof.

4.1 Daily Gain and Loss of Vapors in the Vapor Space

Consider a tank with an internal floating roof, closed vents, and a stationary product level. Each day:

▪ Vapors enter the vapor space: Product evaporates and moves from under the floating roof to the vapor space above the floating roof through deck seams, deck fittings, and rim seals. API *MPMS* Ch. 19.2 gives a method for estimating the amount of evaporative loss that occurs per year, assuming the vapor space above the floating roof is free of vapors (as is assumed to occur in an open-vent tank). This is expressed in terms of an average daily loss as follows:

$$L_{SD19.2} = L_{rd} + L_{dd} + L_{fd} \quad (1)$$

$L_{SD19.2}$ is the sum of the daily rim seal loss L_{rd}, daily deck seam loss L_{dd}, and daily deck fitting loss L_{fd}. The average daily loss is calculated by dividing the annual loss (from API *MPMS* Ch.19.2) by 365 days/yr. To determine the evaporative loss of product in a closed-vent IFRT, $L_{SD19.2}$ must be modified to account for the corresponding gain of vapors (and thus increase in saturation level) in the vapor space.

▪ Vapors exit the vapor space: Vapors in the vapor space expand due to the daytime increase in ambient temperature, and a portion of the vapors are expelled from the vents at the top of the tank if the resulting pressure exceeds the breather vent pressure setting. API *MPMS* Ch. 19.1 gives a method for estimating the amount of vapors that escape through the tank vents annually, assuming that there is a free liquid surface below the vapor space (i.e. no floating roof). This is expressed in terms of an average daily loss as follows:

$$L_{SD19.1} = V_V W_V K_E K_S \qquad (2)$$

$L_{SD19.1}$ is the product of the vapor space volume V_V, the saturated vapor density W_V, the vapor space expansion factor K_E, and the saturation factor K_S. Both K_E and K_S are a function of the saturation of the vapor space, which changes over time.

All vapors in the vapor space will ultimately be exhausted through the vents when the tank is filled.

4.2 Saturation of the Vapor Space for Closed-vent IFRTs

To estimate the concentration of vapors above the floating roof in a closed-vent IFRT, modification is required of the equations for estimating emissions from both floating roof tanks and fixed roof tanks:

▪ The estimated gain (increase) of vapors in the headspace of a freely-vented IFRT [Equation (1)] must be modified to account for the retarding effect of the closed vents on the rate of evaporative loss past an internal floating roof. As the concentration of vapors above the floating roof increases, the expected rate of diffusion through openings in the floating roof decreases from that assumed by API *MPMS* Ch.19.2 for Equation (1) above.

▪ The estimated loss of vapors from the headspace of a fixed-roof tank by daily breathing [Equation (2)] must be modified to account for the retarding effect of the floating roof on the rate of evaporative loss from a fixed-roof tank. To the extent that the concentration of vapors in the vapor space is decreased, the saturation level of the vapors expelled through the fixed-roof vents will be less than that assumed by API *MPMS* Ch.19.1 for Equation (2) above.

In order to make these modifications, we need to know the actual saturation of the vapor space at any given time. API *MPMS* Ch. 19.1 gives an empirically-based method to determine the saturation of vapors at the top of the vapor space K_S as a function of the vapor space height:

$$K_S = \frac{1}{1 + 0.053 P_{VA} H_{VO}} \qquad (3)$$

Although K_S as given by Equation (3) was determined empirically from various conditions of liquid level and number of days from emptying or filling, assume for simplicity that:

▪ K_S is the level of saturation at the top of a half full tank once equilibrium is reached.

▪ The saturation at the liquid surface is 1.0 once equilibrium is reached.

Equation (3) has saturation as a non-linear function of height. In order to determine the average saturation of the vapor space, Equation (3) is evaluated in Table 3 for various product vapor pressures P_{VA} and various outage heights H_{VO} (corresponding to various tank heights).

Table 3—Average Saturation

Product:	diesel	kerosene	gasoline			
			RVP 7	RVP 10	RVP 13	
P_{VA} =	0.00655	0.00832	3.5	5.2	7.0	psia at 60°F
H_{VO} (ft)	s at H_{VO}	s at H_{VO}	s at H_{VO}	s at H_{VO}	s at H_{VO}	
0	1.000	1.000	1.000	1.000	1.000	
1	1.000	1.000	0.844	0.784	0.729	
2	0.999	0.999	0.729	0.645	0.574	
3	0.999	0.999	0.642	0.547	0.473	
4	0.999	0.998	0.574	0.476	0.403	
5	0.998	0.998	0.519	0.421	0.350	
6	0.998	0.997	0.473	0.377	0.310	
7	0.998	0.997	0.435	0.341	0.278	
8	0.997	0.996	0.403	0.312	0.252	
9	0.997	0.996	0.375	0.287	0.230	
10	0.997	0.996	0.350	0.266	0.212	
11	0.996	0.995	0.329	0.248	0.197	
12	0.996	0.995	0.310	0.232	0.183	
13	0.996	0.994	0.293	0.218	0.172	
14	0.995	0.994	0.278	0.206	0.161	
15	0.995	0.993	0.264	0.195	0.152	
16	0.994	0.993	0.252	0.185	0.144	
17	0.994	0.993	0.241	0.176	0.137	
18	0.994	0.992	0.230	0.168	0.130	
19	0.993	0.992	0.221	0.160	0.124	
20	0.993	0.991	0.212	0.154	0.119	
21	0.993	0.991	0.204	0.147	0.114	
22	0.992	0.990	0.197	0.142	0.109	
23	0.992	0.990	0.190	0.136	0.105	
24	0.992	0.990	0.183	0.131	0.101	
25	0.991	0.989	0.177	0.127	0.097	K_s
48' tall,	0.996	0.995	0.382	0.311	0.264	actual average s
H_{VO} =	0.996	0.995	0.589	0.563	0.549	linear average $s = (1 + K_s)/2$
25'	**1.000**	**1.000**	**0.649**	**0.552**	**0.481**	(actual avg s)/(linear avg s) = f_{NL}
40' tall,	0.996	0.995	0.417	0.343	0.293	actual average s
H_{VO} =	0.996	0.995	0.602	0.574	0.557	linear average $s = (1 + K_s)/2$
21'	**1.000**	**1.000**	**0.693**	**0.598**	**0.526**	(actual avg s)/(linear avg s) = f_{NL}
32' tall,	0.997	0.996	0.462	0.384	0.331	actual average s
H_{VO} =	0.997	0.996	0.620	0.588	0.568	linear average $s = (1 + K_s)/2$
17'	**1.000**	**1.000**	**0.744**	**0.653**	**0.582**	(actual avg s)/(linear avg s) = f_{NL}

Saturation is graphed versus height in Figure 1 for a 25 ft tall outage. This shows that low volatility stocks like diesel have a nearly linear saturation, while gasolines have a non-linear saturation. For low volatility stocks like diesel, the saturation is essentially 1.0 over the entire height of the vapor space.

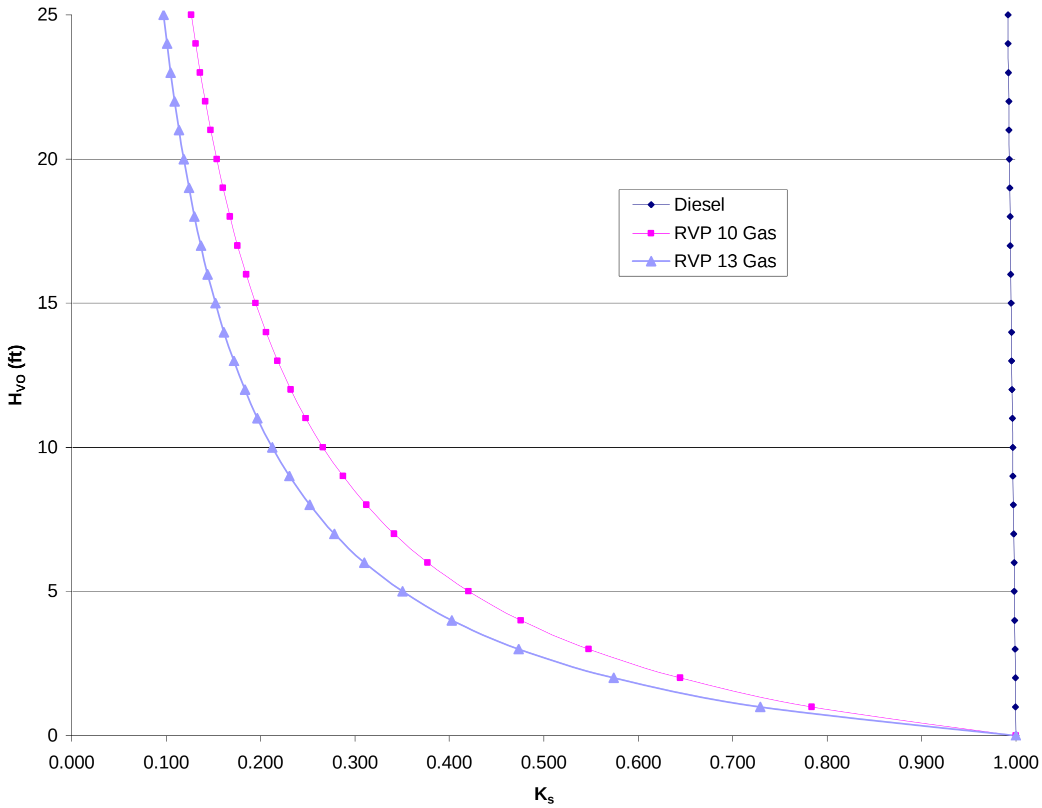

Figure 1—K_s Saturation Factor

Table 3 shows that for stocks with volatility on the order of diesel or kerosene (very low volatility), treating the saturation as a linear function of height has no appreciable effect on accuracy, since the average saturation and the linear average saturation are the same within 3 significant figures. For stocks with the volatility of gasolines, the average saturation is about ½ of the linear average saturation. To account for non-linear distribution of vapors over the height of the vapor space, a non-linear factor f_{NL} can be defined as:

f_{NL} = (actual average s)/(linear average s)

which can be written as

actual average s = f_{NL} (linear average s) (4)

The linear average saturation at equilibrium is the average of the saturation at the top of the tank K_S as given in API *MPMS* Ch.19.1, and the saturation at the liquid surface K_L which is assumed to be 1:

$$s_{eL} = (1 + K_S)/2 \quad (5)$$

The actual average saturation s_e at equilibrium, then, by combining Equations (4) and (5) is

$$s_e = f_{NL}\,(1 + K_S)/2 \quad (6)$$

Before equilibrium is reached, however, the saturation of vapors in the vapor space begins at 0 and increases on a daily basis. The following general expressions describe the variable state of the vapor space:

The average saturation is:

$$s = [(\text{total vapors in the vapor space})/V_V]/W_V \quad (7)$$

The saturation at the top of the tank on day i (K_{Si}) is taken to be K_S times the ratio of the average saturation s on day i to the equilibrium average saturation s_e:

$$K_{Si} = K_S\ s / s_e$$

$$K_{Si} = K_S\ s / [f_{NL}\,(1 + K_S)/2]$$

$$K_{Si} = K_S\ 2s / [f_{NL}\,(1 + K_S)\ ] \qquad (8)$$

And the saturation at the liquid surface (or, if a floating roof is present, immediately above the floating roof) on day i (K_{Li}) is taken to be 1 times the ratio of the average saturation s to the equilibrium average saturation s_e:

$$K_{Li} = (1)\ s / s_e$$

$$K_{Li} = (1)\ s / [f_{NL}\,(1 + K_S)/2]$$

$$K_{Li} = 2\ s / [f_{NL}\,(1 + K_S)] \qquad (9)$$

As a check on Equations (8) and (9), once a state of fixed-roof tank equilibrium is reached, the saturation at the top of the tank K_{Se}, calculated by substituting s_e from Equation (6) into s in Equation (8), is

$$K_{Se} = K_S\ 2\ s_e / [f_{NL}(1 + K_S)] = K_S\ 2[f_{NL}(1 + K_S)/2] / [f_{NL}(1 + K_S)] = K_S$$

as expected, and the saturation at the liquid surface, calculated by substituting s_e from Equation (6) into s in Equation (9), is

$$K_{Le} = 2\ s_e / [f_{NL}(1 + K_S)] = (2)[f_{NL}\ (1 + K_S)/2] / [f_{NL}(1 + K_S)] = 1.0$$

also as expected.

Now that we have established an estimated saturation at the tank top [Equation (8)], we can estimate the daily vapor loss. Similarly, with an estimated saturation at the liquid surface [Equation (9)], we can estimate the daily vapor gain.

4.3 Daily Gain and Loss Equations for Closed-vent IFRTs

The daily gain of vapors G in the vapor space due to evaporation of product is assumed to be a linear function of the saturation level immediately above the floating roof, K_{Li}. The daily gain G is assumed to vary from $L_{SD19.2}$ (when there are no vapors above the floating roof) to 0 (when the air layer immediately above the floating roof is saturated with vapors). The linear decrease of the daily vapor gain G with increase in saturation K_{Li} is expressed as:

$$G = L_{SD19.2}\ (1 - K_{Li})$$

Substituting for K_{Li} per Equation (9):

$$G = L_{SD19.2}\ (1 - 2s/[f_{NL}\,(1 + K_S)] \qquad (10)$$

The daily loss of vapors from the vapor space due to breathing through the vents is estimated by substituting the value for K_S given by Equation (8) into Equation (2):

$$L = V_V\,W_V\,K_E\,K_{Si} = V_V\,W_V\,K_E\,K_S\,2s / [f_{NL}(1 + K_S)] \qquad (11)$$

In Equation (11), the expansion factor K_E accounts for both the volume expansion of the vapors when warmed and the retarding effect of the closed vents on loss. The API *MPMS* Ch. 19.1 documentation file[4] derives

$K_E = \dfrac{\Delta T_V}{T_{LA}} + \dfrac{\Delta P_V - \Delta P_B}{P_A - P_{VX}} \geq 0$ by assuming the vapor space is fully saturated. Given a saturation factor s_1 at time 1 (the minimum daily temperature) and s_2 at time 2 (the maximum daily temperature), a more accurate expression for K_E may be derived, and is:

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{s_2 P_{VX} - s_1 P_{VN} - \Delta P_B}{P_A - s_2 P_{VX}} \geq 0 \quad (12)$$

An approximate value for K_E using the average saturation s may then be written as:

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{s P_{VX} - s P_{VN} - \Delta P_B}{P_A - s P_{VX}} \geq 0 \quad (13)$$

4.4 Example of Closed-vent IFRT Emissions for a 100-day Period

Using Equations (10) and (11), and assuming that the vapor concentration in the vapor space is initially zero, we can estimate the amount of vapors in the vapor space of a given tank over time while the product level remains static.

As an example, consider a 90 ft diameter 48 ft tall closed-vent internal floating-roof tank storing RVP 10 gasoline at 14.5 psi atmospheric pressure, 60°F average temperature, 20°F daily temperature range, and P/V settings of 0.036 and –0.036 psi. The internal floating-roof deck is welded steel with a vapor mounted primary and rim mounted secondary seal.

The daily loss calculated from API *MPMS* Ch.19.2 for this tank with open vents [Equation (1) above] is 11.384 lb/day, and K_S calculated using API *MPMS* Ch.19.1 [Equation (3) above] is 0.138. The vapor space volume V_V is 159,043 ft^3 and the stock vapor density W_V is 0.05598 lb/ft^3. From Table 3, the non-linear saturation factor f_{NL} is 0.552.

<u>Day 1</u>

At the start of day 1 there are no vapors in the vapor space, and thus the average saturation of the vapor space is 0. The gain for day 1 is estimated using Equation (8):

$G = L_{SD19.2}\,(1 - 2s/[f_{NL}\,(1 + K_S)]$

$G = L_{SD19.2}\,(1 - 2s/[0.552(1 + K_S)]) = (11.384\text{ lb})(1 - 2(0)/[0.552(1 + 0.138)]) = 11.384\text{ lb}$

The expansion coefficient K_E for day 1 calculated using Equation (13) is:

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{s P_{V2} - s P_{V1} - \Delta P_B}{P_A - s P_{V2}} = \frac{20}{(60 + 460)} + \frac{0 - 0.072}{14.5 - 0} = 0.0335$$

The loss for day 1 is estimated using Equation (11):

$L = V_V\, W_V\, K_E\, K_{Si} = V_V\, W_V\, K_E\, K_S\, 2s\,/[f_{NL}(1 + K_S)]$

$L = V_V\, W_V\, K_E\, K_S\, 2s\,/[0.552(1 + K_S)] = (159{,}043\text{ ft}^3)(0.05598\text{ lb/ft}^3)(0.0335)(2)(0)/[0.552(1 + 0.138)] = 0$

The total amount of vapors R in the vapor space at the end of day 1 is the vapor in the vapor space at the beginning of day 1 (0), plus the gain, less the loss:

$R = G - L = 11.384 - 0 = 11.384\text{ lb}$

The average saturation of the vapor space at the end of day 1 calculated using Equation (7) is:

s = [(total vapors in the vapor space)/V_V]/W_V = (11.384 lb)/(159,043 ft^3)/(0.05598 lb/ft^3) = 0.00128

<u>Day 2</u>

The gain for day 2 is estimated using Equation (10):

$G = L_{SD19.2}\,(1 - 2s/[f_{NL}(1 + K_S)])$ = (11.384 lb)(1 – 2(0.00128)/[0.552(1 + 0.138)]) = 11.338 lb

The expansion coefficient K_E for day 2 calculated using Equation (13) is:

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{sP_{VX} - sP_{VN} - \Delta P_B}{P_A - sP_{VX}} = \frac{20}{(60+460)} + \frac{0.00128(5.74) - 0.00128(4.73) - 0.072}{14.5 - 0.00128(5.74)} = 0.0336$$

The loss for day 2 is estimated using Equation (11):

$L = V_V W_V K_E K_S 2s/[f_{NL}(1 + K_S)]$ =
(159,043 ft^3)(0.05598 lb/ft^3)(0.0336)(0.138)(2)(0.00128)/[0.552(1 + 0.138)] = 0.167

The total amount of vapors in the vapor space at the end of day 2 is the amount at the end of day 1 (R) plus the gain from day 2 less the loss from day 2:

$R_1 + G_2 - L_2$ = 11.384 + 11.338 – 0.167 = 22.555 lb

The average saturation of the vapor space at the end of day 2 calculated using Equation (7) is

s = [(total vapors in the vapor space)/V_V]/W_V = (22.555 lb)/(159,043 ft^3)/(0.05598 lb/ft^3) = 0.00253

This process can be repeated for each successive day the product level remains stationary. Figure 2 below shows the gain and loss thus calculated for the tank over a 100 day period. Over time, the gain of vapors in the vapor space due to evaporation of product decreases as the vapor concentration of the vapor space increases. Meanwhile, the loss of vapors through the vents increases, also due to the increase in concentration of vapors in the vapor space.

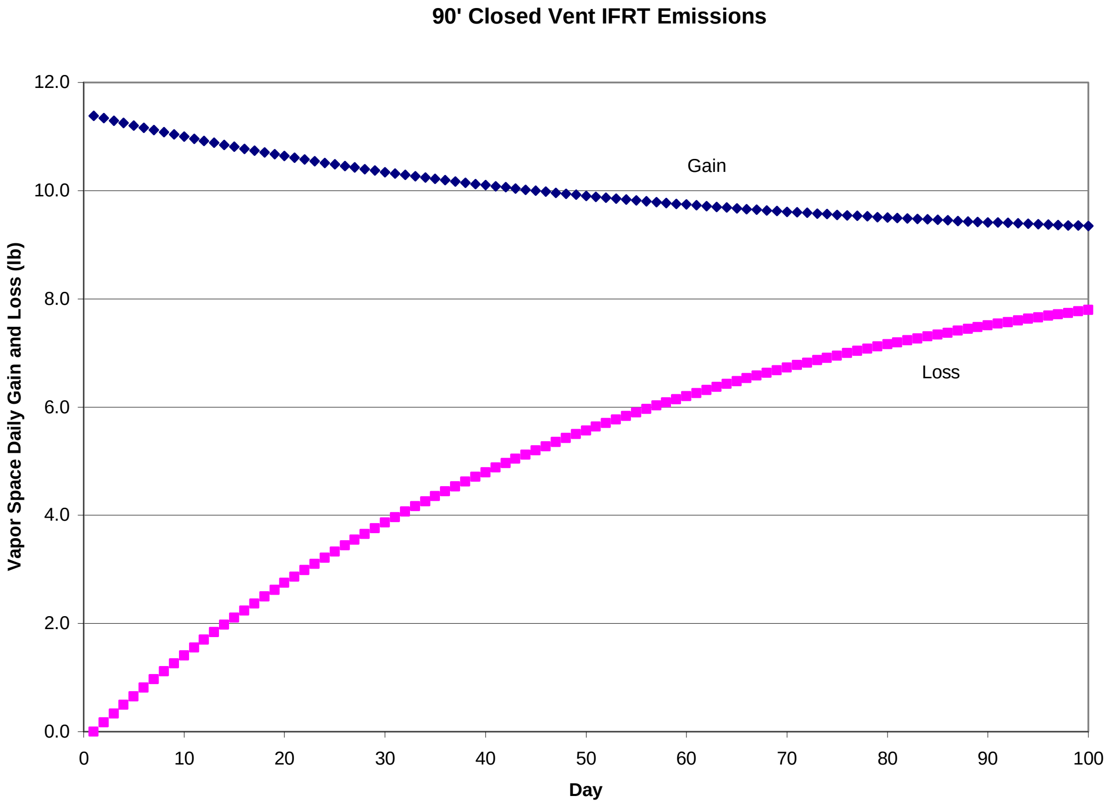

Figure 2—Gain and Loss of Vapors from the Vapor Space

In Figure 2, gain to the vapor space represents vapors escaping past the floating roof. Loss from the vapor space represents vapors being expelled through the fixed-roof vents to the atmosphere due to daily breathing.

Figure 3 shows the total emissions from the same tank over time. The total emissions are taken to be the cumulative vapor loss through the vents plus the vapors in the vapor space, since the vapors in the vapor space will ultimately be exhausted through the vents when the tank is filled.

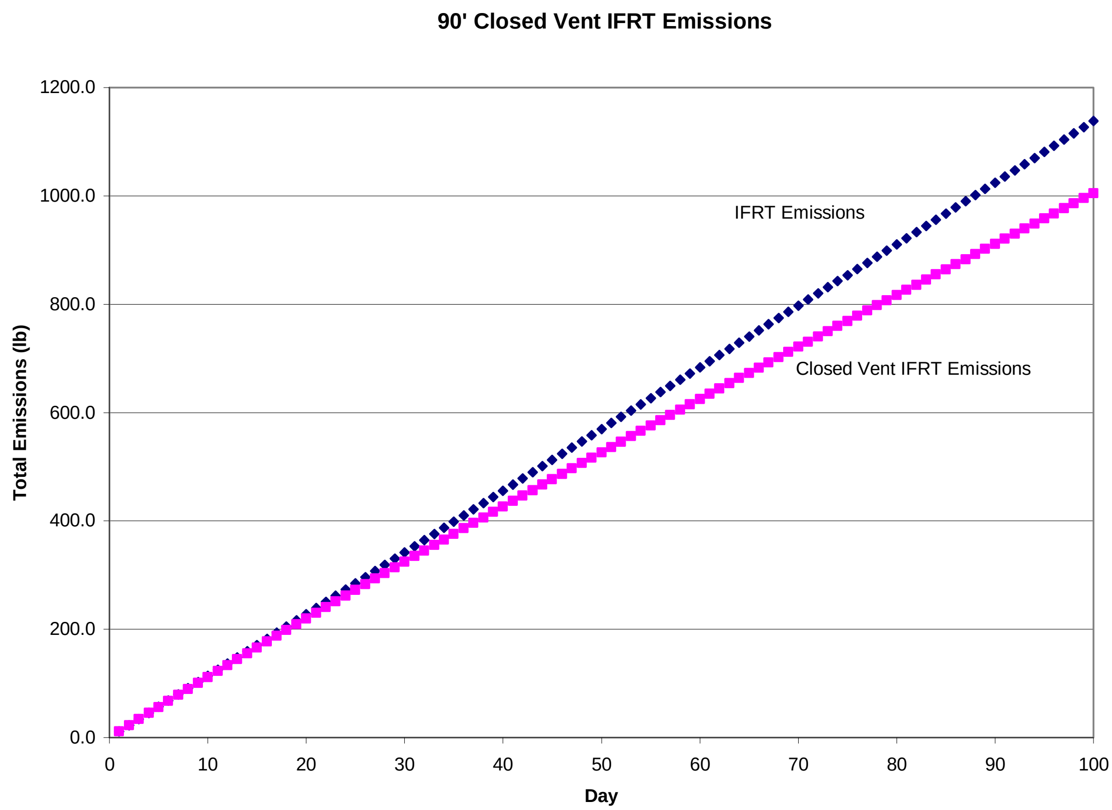

Figure 3—The Effect on Emissions of Adding Closed Vents to an IFRT

Figure 3 shows that the cumulative emissions from the closed-vent IFRT are just slightly less than the emissions from an open-vent IFRT. Even after 100 days (which is only 3.65 turnovers per year), the closed-vent IFRT emissions are 88% of the open-vent IFRT emissions.

5. COMPARING CLOSED-VENT IFRT AND OPEN-VENT IFRT EMISSIONS

To quantify the emission reduction achieved by adding closed vents to an IFRT, the iterative method given in Section 4 was used and the effect of varying parameters was investigated. In the tables comparing closed-vent IFRT emissions to open-vent IFRT emissions, differences of less than 10% are shown shaded.

5.1 Base Case

The base case closed-vent IFRT has:

Product: RVP 13 gasoline
Tank height: 48 ft
Pressure/Vacuum (P/V) setting: +0.30 psi, –0.15 psi
Daily average liquid surface temperature: 60°F
Daily vapor temperature range: 20°F
The internal floating-roof deck is welded steel with a vapor mounted primary and rim mounted secondary seal.

For each case investigated below, closed-vent IFRT emissions are given as the fraction of open-vent IFRT emissions, and the tank diameter *D* and number of days between turnovers *n* were varied as follows:

Tank Diameter *D* (ft)	30	60	90	120

Number of Days Between Turnovers *n*	Turnovers per Year
4	91
7	52
10	37
15	24
20	18
30	12
60	6
90	4

Table 4—Effect of Tank Diameter and Time Between Turnovers on Emissions: (Closed-vent IFRT Emissions)/(Open-vent IFRT Emissions)

Days Between Turnovers	Tank Diameter *D* (ft) RVP 13 Gasoline			
	30	60	90	120
4	0.974	0.990	0.992	0.994
7	0.949	0.980	0.985	0.989
10	0.925	0.970	0.977	0.983
15	0.887	0.955	0.965	0.974
20	0.852	0.939	0.953	0.965
30	0.789	0.910	0.930	0.948
60	0.645	0.835	0.869	0.901
90	0.551	0.774	0.818	0.860

Shading indicates scenarios in which closed vents result in emission reductions of no more than 10% as compared to IFRTs with open vents.

Table 4 shows:

▪ Emission reduction is proportional to the number of days between turnovers. The longer the vapor space stands static, the greater its vapor concentration, which reduces evaporative loss through the floating roof.

▪ Emission reduction is inversely proportional to the tank diameter. Smaller diameter tanks have greater emission reductions.

5.2 Effect of Product Volatility

Two products were considered:

Product	M_V (lb/lb-mole)	P_{VN} (psi at 55°F)	P_{VA} (psi at 60°F)	P_{VX} (psi at 65°F)
Gasoline RVP 13	62	6.36	6.99	7.67
Diesel	130	0.00555	0.00655	0.00771

Table 5—Effect of Product Volatility on Emissions: (Closed-vent IFRT Emissions)/(Open-vent IFRT Emissions)

Days Between Turnovers	Tank Diameter *D* (ft) RVP 13 Gasoline				Tank Diameter *D* (ft) Diesel			
	30	60	90	120	30	60	90	120
4	0.974	0.990	0.992	0.994	0.995	0.998	0.998	0.999
7	0.949	0.980	0.985	0.989	0.989	0.996	0.997	0.998
10	0.925	0.970	0.977	0.983	0.984	0.994	0.995	0.997
15	0.887	0.955	0.965	0.974	0.976	0.991	0.993	0.995
20	0.852	0.939	0.953	0.965	0.968	0.988	0.990	0.993
30	0.789	0.910	0.930	0.948	0.953	0.981	0.986	0.989
60	0.645	0.835	0.869	0.901	0.913	0.965	0.973	0.980
90	0.551	0.774	0.818	0.860	0.881	0.952	0.963	0.972

Table 5 shows:

▪ Emission reduction is proportional to the volatility of the stock. Volatile stocks enter the vapor space more readily, increasing the space's vapor concentration and retarding further evaporation.

5.3 Effect of Type of Floating Roof

Table 6—Effect of Floating Roof Type on Emissions:
(Closed-vent IFRT Emissions)/(Open-vent IFRT Emissions)

Days Between Turnovers	Tank Diameter *D* (ft) IFR = Welded Deck with Vapor Mounted Primary and Rim Mounted Secondary Seals				Tank Diameter *D* (ft) IFR = Bolted Deck with Vapor Mounted Primary and Rim Mounted Secondary Seals			
	30	60	90	120	30	60	90	120
4	0.974	0.990	0.992	0.994	0.967	0.983	0.986	0.988
7	0.949	0.980	0.985	0.989	0.936	0.967	0.972	0.975
10	0.925	0.970	0.977	0.983	0.907	0.951	0.958	0.964
15	0.887	0.955	0.965	0.974	0.861	0.926	0.936	0.944
20	0.852	0.939	0.953	0.965	0.819	0.902	0.915	0.926
30	0.789	0.910	0.930	0.948	0.745	0.857	0.875	0.891
60	0.645	0.835	0.869	0.901	0.586	0.747	0.776	0.802
90	0.551	0.774	0.818	0.860	0.489	0.666	0.701	0.733

Table 6 shows:

▪ Emission reduction is proportional to the rate at which evaporation passes through the floating roof. Floating roofs that allow more vapors to pass through them allow the vapor space's vapor concentration to increase more quickly between turnovers, retarding further evaporation.

5.4 Effect of Tank Height

Table 7—Effect of Tank Height on Emissions:
(Closed-vent IFRT Emissions)/(Open-vent IFRT Emissions)

Days Between Turnovers	Tank Diameter *D* (ft) × 48 ft tall				Tank Diameter *D* (ft) × 32 ft tall			
	30	60	90	120	30	60	90	120
4	0.974	0.990	0.992	0.994	0.970	0.988	0.991	0.993
7	0.949	0.980	0.985	0.989	0.941	0.977	0.982	0.987
10	0.925	0.970	0.977	0.983	0.913	0.965	0.973	0.980
15	0.887	0.955	0.965	0.974	0.870	0.947	0.959	0.969
20	0.852	0.939	0.953	0.965	0.830	0.930	0.945	0.959
30	0.789	0.910	0.930	0.948	0.760	0.897	0.919	0.939
60	0.645	0.835	0.869	0.901	0.610	0.813	0.851	0.886
90	0.551	0.774	0.818	0.860	0.519	0.748	0.796	0.842

Table 7 shows:

▪ Emission reduction is inversely proportional to the tank height. Shorter tanks have greater emission reductions, since the vapor concentration of the vapor space increases more quickly in the smaller outage volume in short tanks.

5.5 Effect of Average Liquid Surface Temperature

Table 8—Effect of Average Liquid Surface Temperature on Emissions: (Closed-vent IFRT Emissions)/(Open-vent IFRT Emissions)

Days Between Turnovers	Tank Diameter *D* (ft), Avg Liquid Surface Temp = 60°F				Tank Diameter *D* (ft), Avg Liquid Surface Temp = 40°F			
	30	60	90	120	30	60	90	120
4	0.974	0.990	0.992	0.994	0.978	0.992	0.994	0.995
7	0.949	0.980	0.985	0.989	0.957	0.983	0.987	0.990
10	0.925	0.970	0.977	0.983	0.937	0.975	0.981	0.986
15	0.887	0.955	0.965	0.974	0.905	0.962	0.971	0.978
20	0.852	0.939	0.953	0.965	0.875	0.949	0.961	0.971
30	0.789	0.910	0.930	0.948	0.822	0.926	0.942	0.957
60	0.645	0.835	0.869	0.901	0.698	0.864	0.892	0.919
90	0.551	0.774	0.818	0.860	0.615	0.814	0.852	0.887

Table 8 shows:

▪ Emission reduction is proportional to the daily average liquid surface temperature T_{LA}. As the daily average liquid surface temperature increases, the vapor concentration of the vapor space increases, retarding further evaporation.

5.6 Effect of Vent Settings

Table 9—Effect of Vent Settings on Emissions: (Closed-vent IFRT Emissions)/(Open-vent IFRT Emissions)

Days Between Turnovers	Tank Diameter *D* (ft), P/V Settings = +0.30/–0.15 psi				Tank Diameter *D* (ft), P/V Settings = +0.031/–0.031 psi			
	30	60	90	120	30	60	90	120
4	0.974	0.990	0.992	0.994	0.974	0.990	0.992	0.994
7	0.949	0.980	0.985	0.989	0.950	0.980	0.985	0.989
10	0.925	0.970	0.977	0.983	0.927	0.971	0.978	0.983
15	0.887	0.955	0.965	0.974	0.892	0.957	0.966	0.975
20	0.852	0.939	0.953	0.965	0.861	0.943	0.956	0.967
30	0.789	0.910	0.930	0.948	0.807	0.918	0.936	0.952
60	0.645	0.835	0.869	0.901	0.699	0.862	0.891	0.917
90	0.551	0.774	0.818	0.860	0.638	0.824	0.859	0.892

Table 9 shows:

▪ Emission reduction is proportional to the pressure/vacuum settings typically used on closed-vent tanks. As the settings increase, less vapors are expelled due to daily expansion of the vapor space, increasing the vapor concentration of the vapor space and retarding further evaporation.

6. THE EQUIVALENT-DIAMETER METHOD

While the iterative method is rational, it is complicated to apply. A simpler method, the equivalent-diameter method, is explained in this section.

6.1 Development

The equivalent-diameter method for estimating closed-vent IFRT emissions postulates that closed-vent floating-roof tank emissions equal those of an emission-equivalent smaller diameter closed-vent tank without a floating roof. The diameter of the smaller emission-equivalent tank is based on the reduction in emissions from the installation of a floating roof in an open-vent tank.

The emission-equivalent tank diameter D_{eq} is determined by setting the liquid surface area of the equivalent-diameter tank equal to the full liquid surface area of the tank of diameter D multiplied by the fraction of open-vent fixed-roof tank loss that is not eliminated by adding a floating roof. For r equals the ratio of open-vent IFRT loss to open-vent fixed-roof tank loss, this can be expressed as:

$$(\pi/4)D_{eq}^2 = (\pi/4)D^2\,(1 - r)$$

Solving for D_{eq},

$$D_{eq} = D\sqrt{1 - r} \qquad (14)$$

For example, if adding a floating roof to a 30 ft diameter open-vent tank reduces emissions by 95.2%, this equation is:

$$(\pi/4)D_{eq}^2 = (\pi/4)(30)^2\,(1 - 0.952)$$

$$D_{eq} = D\sqrt{1 - r} = (30)\ \sqrt{1 - 0.952} = 6.57 \text{ ft}$$

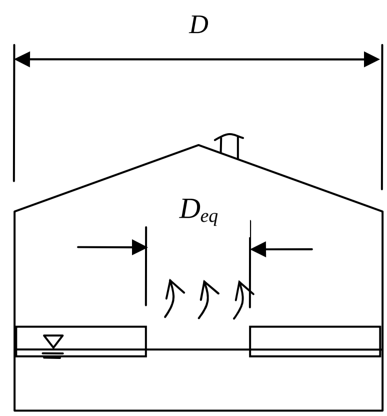

Figure 4—Model of the Equivalent-diameter Tank

The tables below show the loss for RVP 13 gasoline in 48 ft tall tanks with 25 turnovers/yr (14.6 days between turnovers), and 60°F average liquid surface temperature determined by various methods:

(a) using API *MPMS* Ch.19.1 for the tank with open vents and no floating roof;
(b) using API *MPMS* Ch.19.2 for the tank with open vents and a welded deck internal floating roof;
(e) using API *MPMS* Ch.19.1 for an emission-equivalent tank with closed vents set at –0.036 psi, +0.036 psi;
(f) using API *MPMS* Ch.19.1 for an emission-equivalent tank with closed vents set at –0.15 psi, +0.30 psi;
(g) using the iterative method with closed vents set at –0.15 psi, +0.30 psi.

Table 10—Estimated Losses (lb/yr) for Open-vent IFRTs Storing RVP 13 Gasoline

	(a)	(b)	(c)	(d)
Tank Diameter *D* (ft)	Loss per 19.1 for *D* with Open Vents	Loss per 19.2 for *D* with Open Vents	% Reduction IFRT vs FRT, Both Open Vents	Emission-Equivalent Diameter D_{eq} (ft)
30	64,632	2,143	96.7%	5.46
60	258,530	3,295	98.7%	6.77
90	581,692	5,699	99.0%	8.91
120	1,034,119	7,495	99.3%	10.22

Table 11—Estimated Losses (lb/yr) for Closed-vent IFRTs Storing RVP 13 Gasoline

	(e)	(f)	(g)	(h)
Tank Diameter *D* (ft)	19.1 Loss for D_{eq} with P/V 0.036 psi, –0.036 psi	19.1 Loss for D_{eq} with P/V 0.30 psi, –0.15 psi	Iterative Method Loss with P/V 0.30 psi, –0.15 psi	column (f) / column (g)
30	2,120	2,003	1,950	1.03
60	3,260	3,079	3,224	0.96
90	5,639	5,325	5,637	0.94
120	7,415	7,003	7,483	0.94

Column (h) shows that for this case, the equivalent-diameter method results differ from the iterative methods result by no more than 6%.

6.2 Comparing the Iterative and Equivalent-diameter Methods

To compare the iterative and equivalent-diameter methods in more detail, both methods were used to estimate the loss for the 7 cases described below. The varied parameter is shown shaded.

Table 12—Parameters for 7 Closed-vent IFRT Emission Calculation Cases

Case	Product	IFR	Tank Height	T_{LA}	P/V psi	Days/Turnover
1	RVP 13 gas	welded	48 ft	60°F	+0.30/–0.15	15
2	diesel	welded	48 ft	60°F	+0.30/–0.15	15
3	RVP 13 gas	bolted	48 ft	60°F	+0.30/–0.15	15
4	RVP 13 gas	welded	32 ft	60°F	+0.30/–0.15	15
5	RVP 13 gas	welded	48 ft	40°F	+0.30/–0.15	15
6	RVP 13 gas	welded	48 ft	60°F	+0.031/–0.031	15
7	RVP 13 gas	welded	48 ft	60°F	+0.30/–0.15	30

Table 13—Iterative Method vs Equivalent-diameter Method Evaporative Loss (lb/yr)

	Tank Diameter (ft)				Case Description
	30	60	90	120	
Case 1 Open Vents	2,143	3,295	5,699	7,495	base case
Case 1 Iterative	1,897	3,138	5,486	7,282	
Case 1 D_{eq}	2,000	3,076	5,320	6,996	
Case 1 D_{eq}/Iterative	1.054	0.980	0.970	0.961	
Case 2 Open Vents	5	8	11	15	diesel
Case 2 Iterative	5	8	11	15	
Case 2 D_{eq}	4	7	9	12	
Case 2 D_{eq}/Iterative	0.831	0.809	0.804	0.803	
Case 3 Open Vents	2,687	5,471	10,594	16,197	bolted IFR
Case 3 Iterative	2,310	5,058	9,902	15,280	
Case 3 D_{eq}	2,508	5,106	9,889	15,119	
Case 3 D_{eq}/Iterative	1.086	1.010	0.999	0.989	
Case 4 Open Vents	2,142	3,292	5,695	7,489	tank ht = 32 ft
Case 4 Iterative	1,861	3,113	5,453	7,250	
Case 4 D_{eq}	1,966	3,022	5,228	6,875	
Case 4 D_{eq}/Iterative	1.057	0.971	0.959	0.948	
Case 5 Open Vents	1,306	2,008	3,473	4,567	T_{LA} = 40°F
Case 5 Iterative	1,197	1,936	3,375	4,467	
Case 5 D_{eq}	1,218	1,874	3,240	4,261	
Case 5 D_{eq}/Iterative	1.018	0.968	0.960	0.954	
Case 6 Open Vents	2,143	3,295	5,699	7,495	P/V = +0.031/–0.031
Case 6 Iterative	1,908	3,144	5,495	7,291	
Case 6 D_{eq}	2,123	3,264	5,646	7,425	
Case 6 D_{eq}/Iterative	1.113	1.038	1.027	1.018	
Case 7 Open Vents	2,141	3,291	5,693	7,487	30 days/ turnover
Case 7 Iterative	1,688	2,993	5,289	7,087	
Case 7 D_{eq}	1,928	2,963	5,126	6,741	
Case 7 D_{eq}/Iterative	1.142	0.990	0.969	0.951	

For all cases considered above other than diesel, the equivalent-diameter method estimates are within 14% above (Case 7) and 5% below (Case 4) the iterative method.

In the case of stocks with volatility as low as diesel's, equivalent-diameter method emissions are 20% less than iterative method emissions. The difference in emissions estimated by the two methods is no more than 3 lb/yr, however.

In addition to the above comparisons, the iterative and equivalent-diameter methods are compared graphically below for 6 tank diameters (15, 30, 45, 60, 90, and 120 ft), three products (RVP 7 and RVP 13 gasoline, and diesel), and 3 turnover rates (5, 15, and 90 days between turnovers). Other parameters were from the Case 1 above.

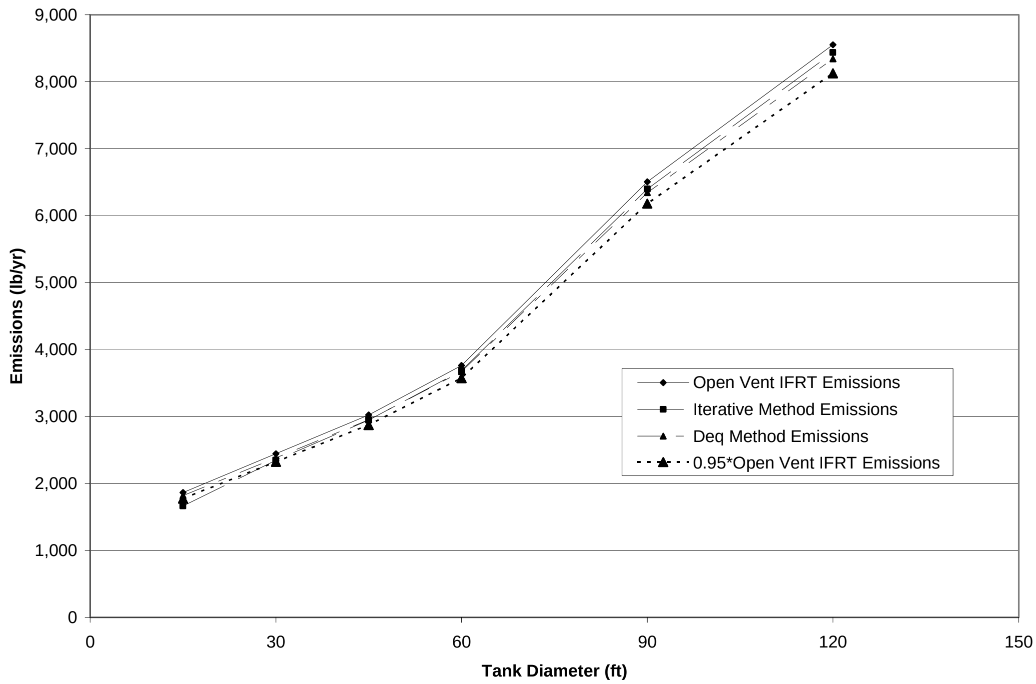

Figure 5—RVP 13 Gasoline Equivalent-Diameter vs Iterative Method 5 Days Between Turnovers

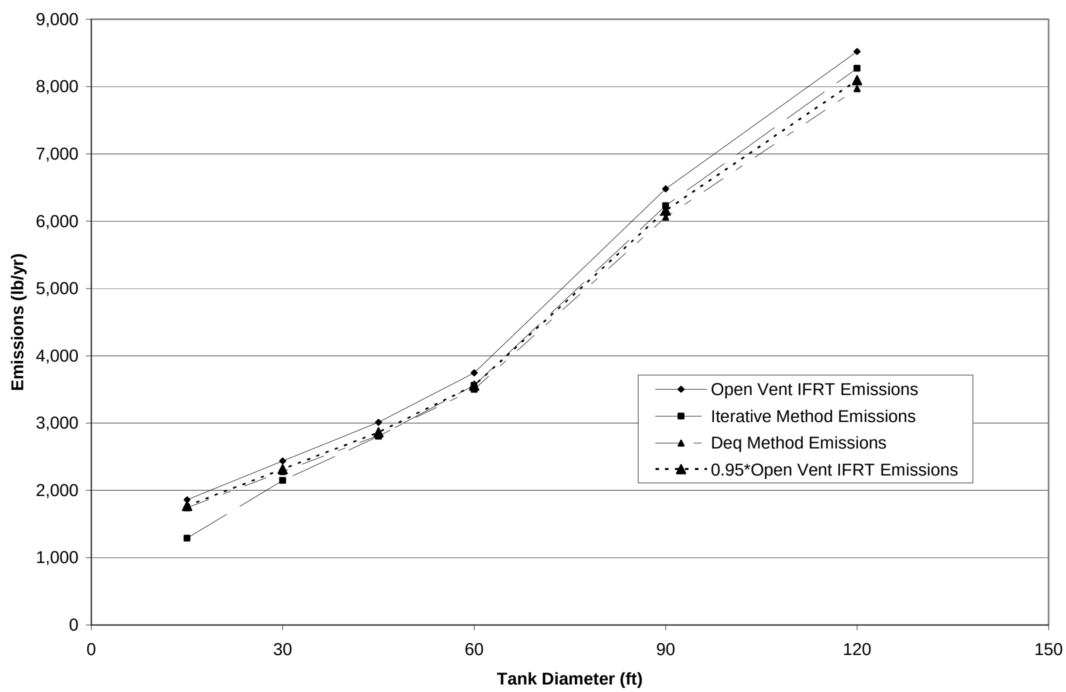

Figure 6—RVP 13 Gasoline Equivalent-Diameter vs Iterative Method 15 Days Between Turnovers

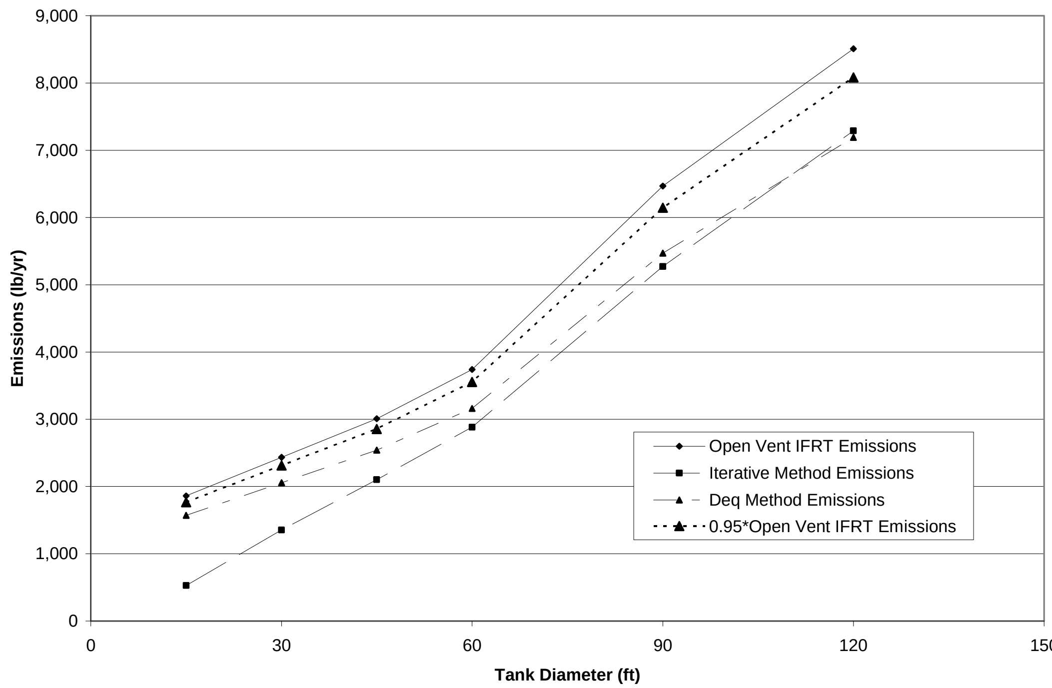

Figure 7—RVP 13 Gasoline Equivalent-diameter vs Iterative Method 90 Days Between Turnovers

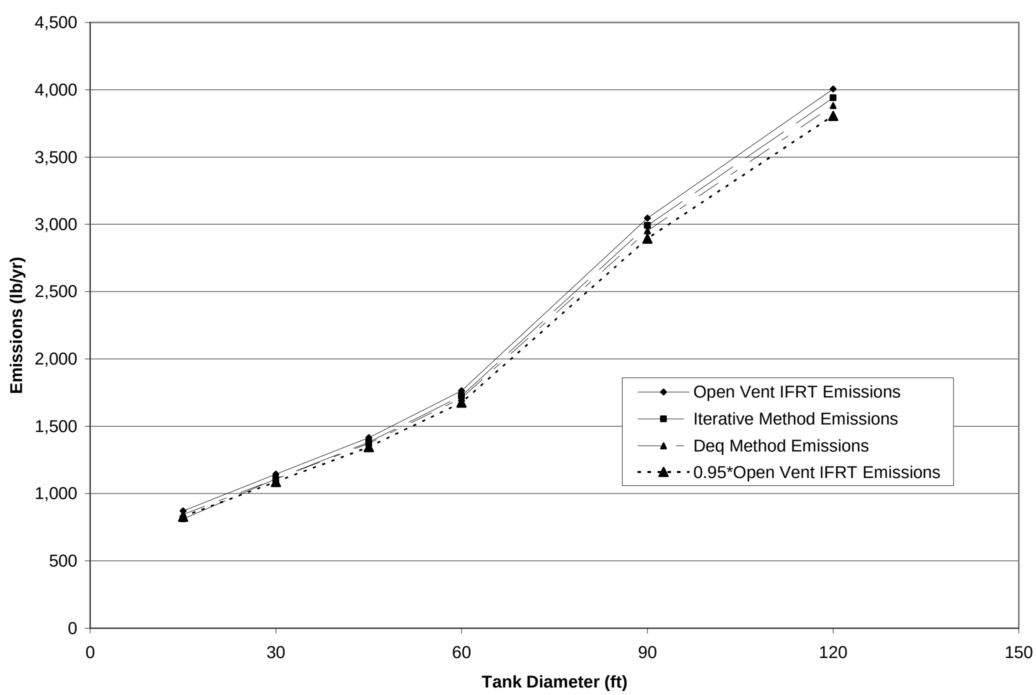

Figure 8—RVP 7 Gasoline Equivalent-diameter vs Iterative Method 5 Days Between Turnovers

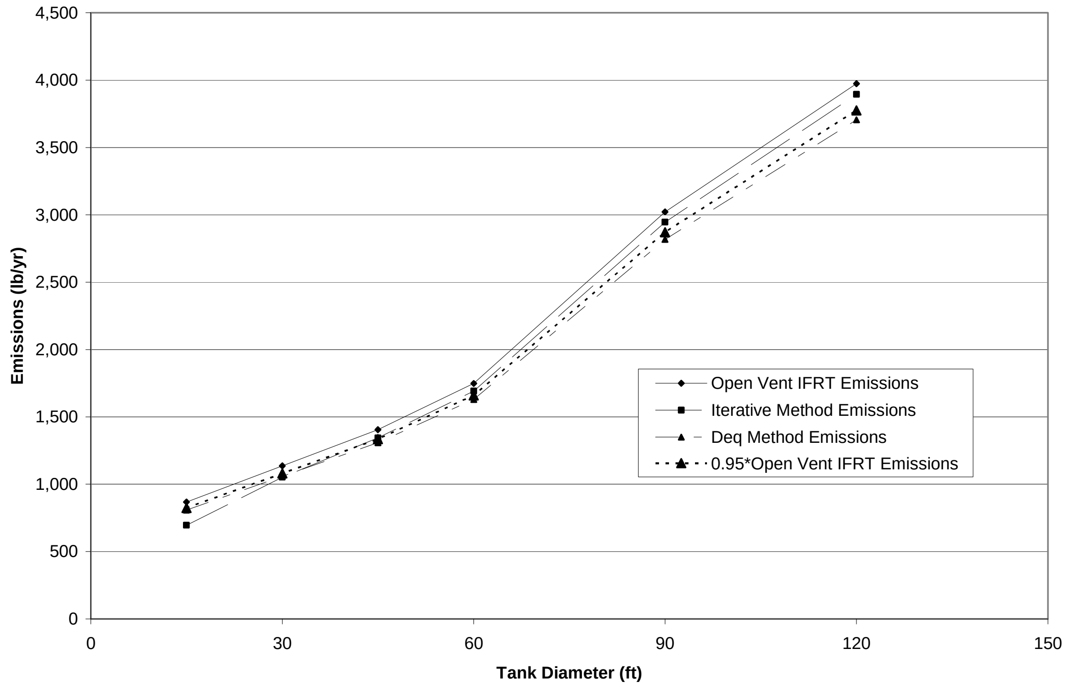

Figure 9—RVP 7 Gasoline Equivalent-diameter vs Iterative Method 15 Days Between Turnovers

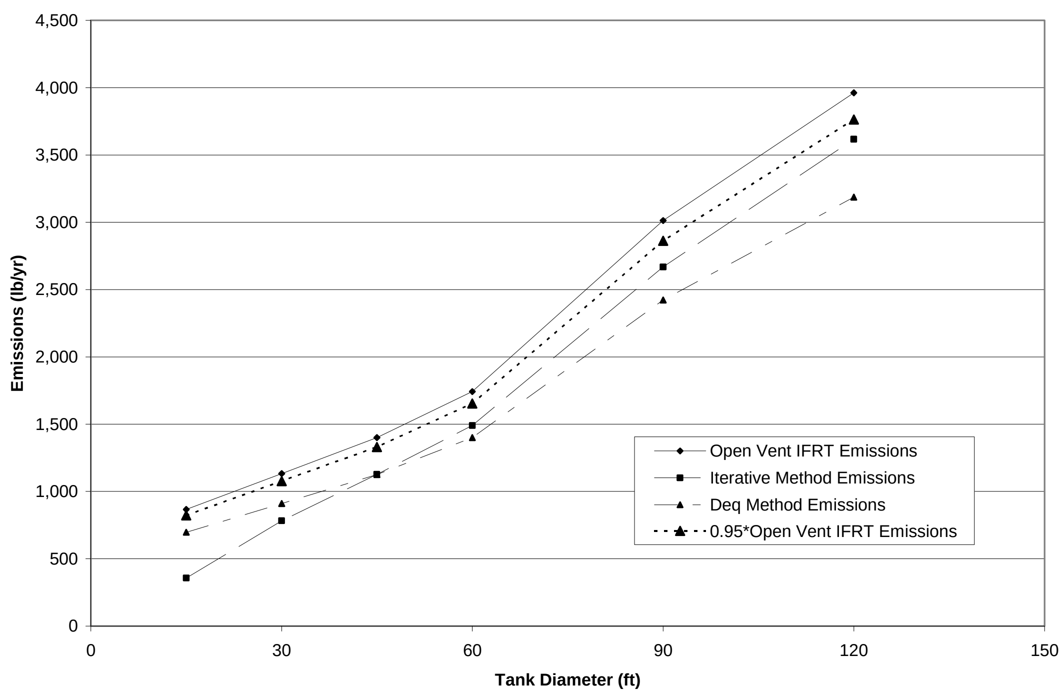

Figure 10—RVP 7 Gasoline Equivalent-diameter vs Iterative Method 90 Days Between Turnovers

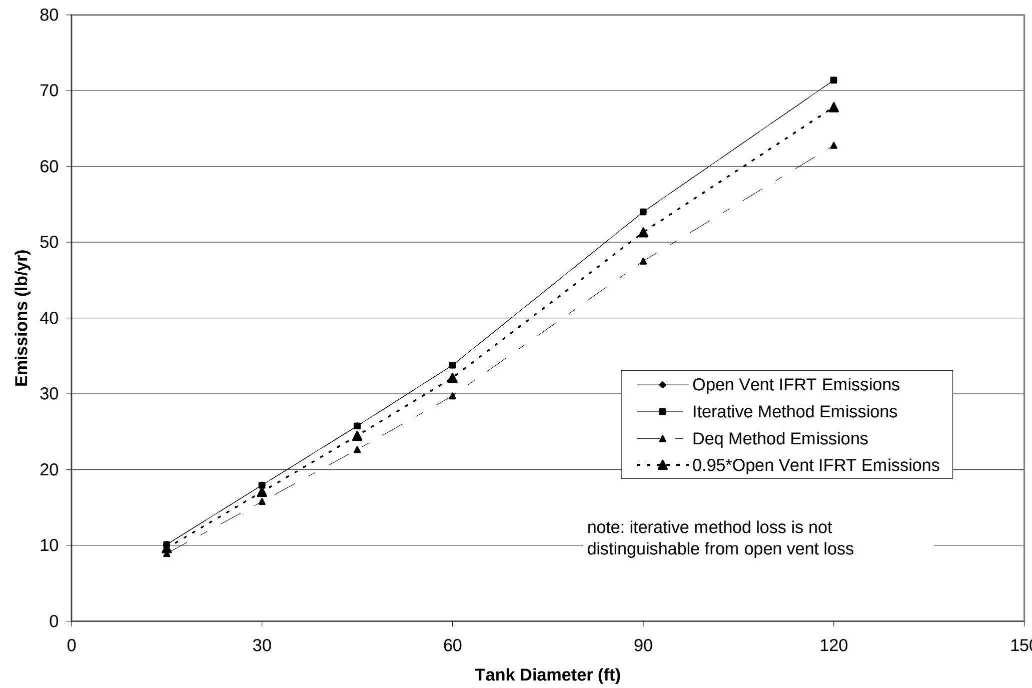

Figure 11—Diesel Equivalent-diameter vs Iterative Method 5 Days Between Turnovers

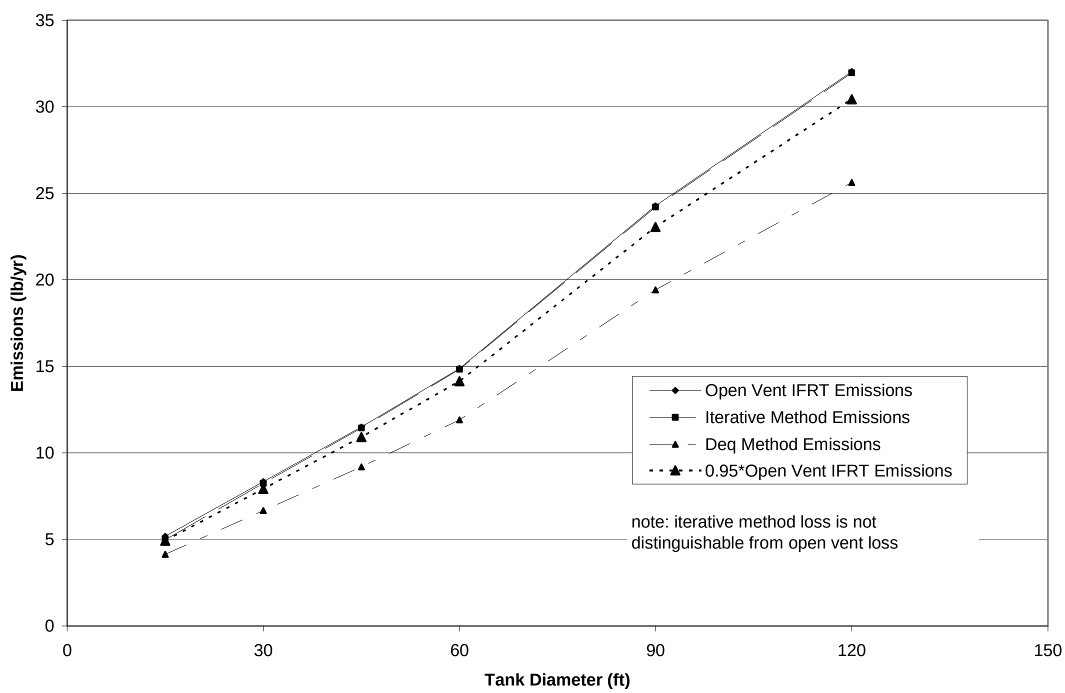

Figure 12—Diesel Equivalent-diameter vs Iterative Method 15 Days Between Turnovers

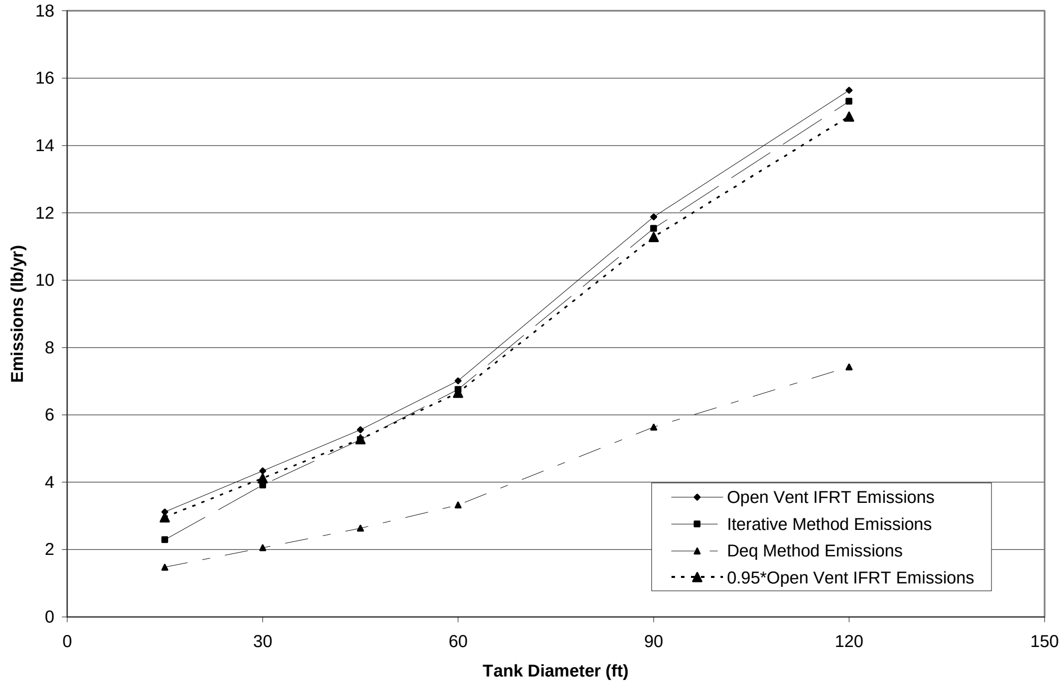

Figure 13—Diesel Equivalent-diameter vs Iterative Method 90 Days Between Turnovers

7. THE GERMAN METHOD

The German document VDI 3479[6] provides a method for estimating the evaporative loss from closed-vent internal floating-roof tanks as:

$$L_T = (1 - \eta_{SD})[(1 - \eta_{VD})\, f\, L_S + L_W]$$

This equation is similar to API *MPMS* Ch. 19.1 (for fixed-roof tanks without a floating roof) in that it estimates the total loss as the sum of the standing loss L_S and the working loss L_W. A factor that accounts for the reduction of evaporation due to the floating roof $(1 - \eta_{SD})$ is applied to both types of losses. Also, factors that account for the effect of the closed vents $(1 - \eta_{VD})$, and coatings (f) are applied to the standing loss. These parameters are accounted for in API *MPMS* Ch. 19.1 in a similar, but not identical, manner.

This estimation method is convenient but flawed. It assumes that the floating roof efficiency is the same for closed-vent tanks as for freely-vented tanks since it simply applies the floating roof efficiency to the fixed roof closed-vent tank loss. Internal floating roof loss factors were developed on the basis of tests with fresh air on the top side of the floating roof, but closed-vent tanks have a partially saturated vapor space above the roof. Therefore, evaporative loss through the floating roof may be different in closed-vent tanks than in freely-vented tanks.

Furthermore, the German method reduces estimated standing loss due to the closed vents but overlooks that this results in more vapors being retained in the tank to be eventually expelled by filling. It assumes the filling loss to be reduced by the floating roof efficiency, whereas in reality if there is sufficient time between fillings, the vapor space may reach the same level of saturation as it would if there were no floating roof, and filling loss would not be reduced at all. (As discussed in the iterative method, however, the tank may reach a state of balance at a lower level of saturation than would occur for a fixed-roof tank, resulting in lower filling losses regardless of the time between fillings.)

In conclusion, the German method is relatively simple, but it overlooks some of the complexities of the problem.

8. FLAMMABLE MIXTURES IN THE VAPOR SPACE

The iterative method determines the saturation of the vapor space at the end of each day the product level remains static. The saturation typically increases slowly as vapors from under the floating roof enter the vapor space at a faster rate than they leave through the tank vents. This saturation can be compared to the saturation corresponding to the lower explosive limit (LEL) and upper explosive limit (UEL) for a given product and system pressure.

This method was used to investigate the flammability of the vapor space for various tank diameters storing RVP 13 gasoline (which has an LEL of 0.014 and a UEL of 0.076 concentration by volume[5]) in a tank with a pressure setting of 0.30 psi. This concentration is converted to saturation as follows:

s = (concentration by volume)/[$P_{VX}/(P_A + P_{BP})$]
s at LEL = 0.014/[7.67/(14.5 + 0.30)] = 0.027
s at UEL = 0.076/[7.67/(14.5 + 0.30)] = 0.147

	Tank Diameter (ft)			
Number of Days After Initial Fill:	30	60	90	120
to reach LEL	6	16	21	29
to reach UEL	53	> 200	> 200	> 200

This shows that large gasoline tanks that turn over frequently usually do not enter the explosive range. However, small diameter gasoline tanks may enter and remain in the explosive range for extended periods after initial filling. This is illustrated by the 30 ft diameter tank in the example above, which enters the explosive range 6 days after initial fill to the tank's half height and remains in the explosive range for 47 days if the product level remains stationary.

Furthermore, as shown in section 4.2, the vapor concentration in the vapor space is not uniform, but rather is stratified with a higher concentration of vapors at the bottom of the vapor space. This means that explosive concentrations occur even sooner than predicted by assuming uniform vapor concentration.

9. ADVANTAGES AND DISADVANTAGES OF OPEN-VENT IFRTS AND CLOSED-VENT IFRTS

The advantages of using closed vents on IFRTs are:

▪ Evaporative loss is slightly reduced with closed vents. This reduction is negligible, however, for low volatility products such as diesel or kerosene, large tanks, low P/V settings, or frequent turnovers.

▪ Closed-vent IFRTs may be used to protect product purity for products that are extremely sensitive to water content. This may be achieved by having inert gas drawn into the tank when the tank pressure drops, thereby avoiding the entry of moist ambient air.

The disadvantages of using closed vents on IFRTs are:

▪ The vapor space is more likely to be in the explosive range with closed vents versus open vents unless inert gas blankets are used. Since safety is a foremost issue, this seriously discourages the use of closed vents for storing products such as gasoline.

▪When the vents in the fixed roof of an IFRT are closed, rather than open, emission estimates become more complicated and have greater uncertainty.

▪ Closed-vent tanks can be damaged if vents do not operate properly, risking liquid spills.

▪ Vapors escape past the floating roof at nearly the same rate for closed-vent and open-vent IFRTs, but the timing of vapors leaving the tank is significantly affected. By retaining vapors within the tank, short term emissions experienced during filling may be higher for a closed-vent IFRT.

10. SUMMARY

This report shows:

▪ Emissions from closed-vent IFRTs are slightly less than emissions from open-vent IFRTs. It is conservative to use open-vent IFRT emissions to estimate closed-vent IFRT emissions.

▪ Two methods are presented for estimating closed-vent IFRT emissions: the iterative method and the equivalent-diameter method. The only assumption used in the iterative method that is not taken from API *MPMS* Ch. 19.1 and *MPMS* Ch. 19.2 is that evaporation rate is a linear function of the saturation of the vapor space. The iterative method is more rational while the equivalent-diameter method requires less computational effort.

▪ Estimating emissions from a closed-vent IFRT is shown to be highly complex. The most rational method presented in this report (the iterative method) is too cumbersome for general use, but the simpler equivalent-diameter method significantly underestimates emissions for certain cases. The reduction in emissions afforded by adding closed vents to an IFRT is shown to be less than 10% for most scenarios. Therefore, a simple 5% reduction applied to all scenarios appears to be the most reasonable approach.

▪ Stock volatility, turnover rate, the rate at which evaporation passes through the floating roof, tank height, P/V settings, and daily average liquid surface temperature affect the emission reduction of a closed-vent floating-roof tank versus an open-vent floating-roof tank. Because the absolute reduction is relatively insensitive to tank diameter, the percentage reduction for adding closed vents to an IFRT is only significant for small diameter tanks. Variations that increase the vapor concentration of the tank's vapor space have the effect of decreasing emissions. This occurs because evaporation through the floating roof is retarded as the vapor space's vapor concentration increases. If the vapor space were to reach saturation, no evaporation would occur.

Table 14—Effect of Various Parameters on Closed-vent IFRT Emissions vs Open-vent IFRT Emissions

Parameter	Effect on Closed-Vent Emissions vs Open-Vent Emissions:
as stock volatility increases	emission reduction increases
as number of days between turnovers increases	emission reduction increases
as tank diameter increases	emission reduction decreases
as permeability of the floating roof increases	emission reduction increases
as tank height increases	emission reduction decreases
as daily average liquid surface temperature increases	emission reduction increases
as P/V settings increase	emission reduction increases

▪ Closed-vent IFRTs can contain a flammable mixture in the vapor space, especially in small diameter tanks that stand idle for more than a few days. When this has occurred, the vapors that are vented while the tank is being filled may be flammable. On the other hand, an open-vent IFRT is intended to keep the vapor space out of the explosive range (i.e. below the lower explosive limit). Therefore, venting open-vent IFRTs is safer than venting closed-vent IFRTs.

11. CONCLUSION

Emissions reductions from adding closed vents to IFRTs were found to be significant only for small diameter tanks storing volatile liquids with infrequent turnovers. For low volatility stocks such as diesel, the emission reductions due to adding closed vents are generally less than 10% regardless of the tank diameter or frequency of turnovers. For IFRTs 60 ft in diameter and larger, experiencing 18 or more turnovers per year, the emission reductions due to adding closed vents are generally less than 10%, regardless of the liquid stored or the vent settings on the tank (assuming that the pressure setting is not so high as to require the tank to be anchored). For estimating emissions, a 5% reduction applied to all scenarios is the recommended approach.

12. REFERENCES

[1] American Petroleum Institute, *MPMS* Chapter 19.1, *Evaporative Loss from Fixed-roof Tanks*, Third Edition, March 2002, Washington, D.C.

[2] American Petroleum Institute, *MPMS* Chapter 19.2, *Evaporative Loss from Floating-roof Tanks*, Second Edition, September 2003, Washington, D.C.

[3] American Petroleum Institute, API Standard 650 *Welded Steel Tanks for Oil Storage*, Eleventh Edition, June 2007, Washington, D.C.

[4] American Petroleum Institute, Chapter 19.1D, *Documentation File for API Manual of Petroleum Measurement Standards* Chapter 19.1, *Evaporative Loss from Fixed-Roof Tanks*, First Edition, March 1993, Washington, D.C.

[5] National Fire Protection Association, NFPA 325, *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*, 1994 Edition, Quincy, Massachusetts.

[6] VDI 3479 *Emission Control—Marketing Installation Tank Farms*, July 1985.

APPENDIX A—NOMENCLATURE

Symbol	Units	Description
D	ft	tank diameter
D_{eq}	ft	tank diameter for the same emissions using API *MPMS* Ch. 19.1 with open vents as from API *MPMS* Ch.19.2
f	–	coating factor (VDI 3479)
F_{rd}	lb-mole/day	rim seal loss factor (API *MPMS* Ch.19.2)
F_{fd}	lb-mole/day	fitting loss factor (API *MPMS* Ch.19.2)
F_{dd}	lb-mole/day	deck seam loss factor (API *MPMS* Ch.19.2)
G	lb/day	daily gain in vapors in the vapor space due to product evaporation
H_{VO}	ft	vapor space outage (or height) (API *MPMS* Ch.19.1)
K_C	–	product factor (API *MPMS* Ch.19.2)
K_E	–	vapor space expansion factor (API *MPMS* Ch.19.1)
K_L	–	saturation factor at the liquid surface
K_S	–	saturation factor at the top of the tank (API *MPMS* Ch.19.1)
K_{Smax}	–	upper limit on saturation factor
L	lb/day	daily loss in vapors in the vapor space due to heating
L_S	lb/yr	standing storage loss per year
$L_{S19.1}$	lb/yr	standing storage loss per year for a closed-vent fixed-roof tank
$L_{SD19.1}$	lb/day	standing storage loss per day for a closed-vent fixed-roof tank
$L_{SD19.2}$	lb/day	standing storage loss per day for a freely-vented internal floating-roof tank
L_T	lb/yr	total loss per year
L_W	lb/yr	working loss per year
M_V	lb/lb-mole	stock vapor molecular weight
n	days	number of days between turnovers (tank fills)
P^*	–	vapor pressure function (API *MPMS* Ch.19.2)
P_A	lb/in.^{2}	atmospheric pressure
P_{BP}	lb/in.^{2}	breather vent maximum pressure setting
P_{BV}	lb/in.^{2}	breather vent minimum pressure setting
P_{VA}	lb/in.^{2}	stock vapor pressure at the average daily liquid surface temperature
P_{VN}	lb/in.^{2}	stock vapor pressure at the minimum daily liquid surface temperature
P_{VX}	lb/in.^{2}	stock vapor pressure at the maximum daily liquid surface temperature
ΔP_B	lb/in.^{2}	breather vent setting range (API *MPMS* Ch.19.1)
ΔP_V	lb/in.^{2}	stock daily vapor pressure range
r	–	ratio of internal floating-roof loss to fixed-roof tank loss, both with open vents
R	lb	weight of vapors residing in the vapor space
s	–	average saturation of the vapor space
s_1	–	vapor space saturation factor at the minimum daily temperature
s_2	–	vapor space saturation factor at the maximum daily temperature
ΔT_V	^oR	daily vapor temperature range
T_{LA}	^oR	daily average liquid surface temperature
V_V	ft^3	vapor space volume
W_V	lb/ft^3	saturated vapor density

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