Documentation for Proposed Changes to AP-42 Chapter 7 Section 7.1 – Organic Liquid Storage Tanks 2018

Proposed Revisions:

References to section and paragraph numbers pertain to the numbering in the draft proposal.

1) Editorial.

   a. Performed wordsmithing throughout for clarity, consistency and correctness.

   b. 7.1.1.1 Added a new section titled Scope, to provide an overview of the chapter.

   c. 7.1.3.2 Separated the calculation of standing loss from the calculation of working loss for floating-roof tanks, rather than having the two intertwined.

2) Nomenclature.

   a. Edited variable labels for consistency and updated Table 7.1-1 accordingly.

3) Scope.

   a. Added a Scope section up front, to explain the scenarios for which the document is and is not intended.

4) TANKS 4.09

   a. Added commentary that the software program TANKS 4.09, which has not been updated to incorporate these revisions, has known errors and is no longer supported by EPA.

5) Equations.

   a. See Appendix A for a summary of the disposition of each equation.

   b. Temperature Equations. [see Appendix B] The temperature equations that have been in AP-42 Chapter 7.1 were derived in API Publication 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. The original development of these equations took place prior to the proliferation of desktop computers, and thus there was a tendency to make approximations and substitutions that would simplify the calculations. Given the present accessibility to computers, however, such simplifications are unnecessary, and the equations have been revised to more accurately reflect the theoretical derivations. Development of the revised temperature equations is summarized in Appendix B of this document and presented in more detail in Annex I of API MPMS Chapter 19.4, "Evaporative Loss Reference Information and Speciation Methodology," Third Edition, October 2012.

      i. Specifically, edited the coefficients in the default expressions for T_{LA} and ΔT_V to be based on a uniform assumption of 0.5 for the tank height-to-diameter ratio (H/D), expressed these coefficients to one significant figure, and added a more general form of these equations with H/D as a variable.

      ii. Added text advising that the equation for calculating T_B from an assumption of equilibrium with ambient conditions should be used only for tanks that may be reasonably assumed to be in equilibrium with the atmosphere and for which measured liquid bulk temperatures are not available. That is, it is always preferable to use measured liquid bulk temperature data rather than to calculate the liquid bulk temperature from an assumption of equilibrium with ambient atmospheric conditions.

iii. Also, replaced the former equation for calculating T_B from ambient conditions, which did not account for the amount of solar radiation striking the tank, with an equation developed from the same theoretical energy transfer model from which the other temperature equations were developed.

iv. Added separate equations to calculate T_{LA} for floating-roof tanks, with separate equations for different types of floating roof decks.

v. Also added separate equations to calculate T_B for floating-roof tanks that are in equilibrium with the atmosphere and for which measured liquid bulk temperatures are not available.

c. Alternative Equations. Added language to clarify, in the instances of alternative equations, which equations are preferred as being more accurate. This pertains particularly to the equations for K_E, ΔP_V, and L_W for fixed-roof tanks.

i. K_E. Clarified that Equation 1-5 (formerly Equation 1-7) is the general and preferred form of equation for calculating K_E, and that the simpler expressions for K_E in Equations 1-12 and 1-13 are approximations that are acceptable when certain criteria are met. Also added text explaining that the value of K_E cannot be greater than 1.

ii. ΔP_V. Recommended that the range in vapor pressure, ΔP_V, should always be calculated directly as ($P_{VX} - P_{VN}$), the difference between the maximum and minimum vapor pressures, and not by means of the old alternative. Moved the old alternative approximation for ΔP_V to a new section for historical equations that are no longer recommended. This approximation had simplified the calculation of ΔP_V by avoiding the need to calculate P_{VX} and P_{VN}. However, it sometimes introduced significant error and is now unnecessary given computer tools for performing calculations.

iii. L_W. Recommended that the fixed-roof tank working loss, L_W, should always be calculated from the general form of equation that retains temperature as a variable, and not by means of the old alternative. Moved the old alternative approximation for L_W to a new section for historical equations that are no longer recommended.

d. Vapor Space Temperature. Added an equation for calculating the temperature of the vapor space, T_V. It is used in Equation 1-22 for calculation of the stock vapor density, W_V, which previously used the average liquid surface temperature, T_{LA}, as an approximation of the vapor space temperature. See Appendix B for the derivation of this equation.

e. Vapor Density. Revised the calculation of vapor density to use the vapor space temperature rather than use the liquid surface temperature as an approximation of the vapor space temperature.

f. Net Throughput. Provided guidance explaining that net throughput is most accurately based on changes in liquid level, rather than pumping volume, for tanks in which pump in and pump out occur at the same time, and revised the equations to accommodate use of accumulated changes in liquid level.

6) True Vapor Pressure.

a. Explained how this term is defined for purposes of this document, and updated guidance on how true vapor pressure values may be determined.

b. Added a reference to ASTM D6377 for measuring the true vapor pressure of crude oil.

c. Added a reference to ASTM D5191 as an acceptable alternative to ASTM D323 for determining Reid vapor pressure.

7) Pressurized Tanks.

a. Explained that the equations for standing and working losses from fixed-roof tanks account for vent settings, and are thus applicable to pressurized tanks which may vent to the atmosphere when filling.

b. Also explained that the equations are not applicable to cases where the vent settings are sufficiently high that the tank is designed to not vent to atmosphere. In such cases, leakage through the vents is estimated as equipment leaks rather than as storage tank emissions.

8) Insulated Tanks.

a. Added guidance for estimating emissions from fully insulated tanks (i.e., both shell and roof are insulated). This guidance includes an assumption of the liquid surface temperature being equal to the liquid bulk temperature, in that there is minimal heat loss through the roof or shell of the tank.

b. It also assumes no generation of breathing loss from the ambient diurnal temperature cycle in that there is minimal heat transfer through the roof and shell of the tank.

c. The guidance explains, however, that a fully insulated tank may have breathing losses driven by temperature cycles in the heating of the liquid stock and provides equations to estimate such heating-cycle losses.

9) Partially Insulated Tanks.

a. Added guidance that a partially insulated tank (i.e., shell is insulated but roof is not) may be modeled as an uninsulated tank in that significant heat transfer will take place through the tank roof.

b. Alternatively added temperature equations for more accurate modeling of partially insulated tanks, rather than modeling as not insulated. See Appendix B.

10) Distillate Flushing.

a. Added a brief discussion of distillate flushing in the sections on Floating Roof Landings and Tank Cleanings. This refers to flooding the bottom of a nearly empty tank with a light distillate such as diesel to reduce the vapor pressure of a more volatile stock such as gasoline.

b. This discussion is qualitative and does not include equations.

11) Floating Roof Landing Emissions.

a. Added text suggesting that emissions from a landing for which the duration is less than a day may be estimated by prorating the estimated emissions for a one-day landing event to the portion of the day involved.

b. Added an upper limit on the estimated refilling loss.

c. K_E. The procedure for estimating floating roof landing loss had calculated K_E using the old approximation for ΔP_V, which has been moved to the section for historical equations that are no longer recommended. The revised text cites the equations now given for K_E in the section for fixed-roof tanks, in which ΔP_V is calculated directly as ($P_{VX} - P_{VN}$).

12) Tank Cleaning Emissions.

a. Added a section for estimating emissions resulting from the cleaning of storage tanks.

b. The methodology is specifically for estimation of emissions while forced ventilation is operating in the tank, regardless of whether or not cleaning operations are taking place.

13) Flashing Emissions.

a. Added a section for estimating emissions resulting from flashing.

14) Short Time Periods.

a. Added explanation for why the equations for routine emissions should not be used for time periods shorter than one month.

15) Special Cases.

a. Added references to API publications for selected special cases:

i. Internal floating-roof tanks with closed vent systems. This refers to internal floating-roof tanks that vent to the atmosphere, but which have self-closing vents rather than the more typical open vents. Reference is made to an API document, with a recommendation of simply applying a 5% reduction from the estimated emissions for a freely vented internal floating-roof tank.

ii. Case-specific liquid surface temperature. This refers to accounting for certain parameters which have default values assigned in the development of the equations for this document. These parameters include the height-to-diameter ratio of the tank and the thermal resistance of the floating roof. However, equations with the height-to-diameter ratio as a variable have been added to the proposed revision, and thus this section may now be extraneous.

16) Figures.

a. Added figures for the slotted guidepole “flexible enclosure” and the guidepole/ladder combination “ladder sleeve.”

17) Tables.

a. Replaced old tables with updated tables from API MPMS 19.4, including:

i. Table 7.1-2. Properties of Selected Petroleum Stocks. Revised the default vapor pressure constants for No. 6 Fuel Oil and added Vacuum Residual Oil as a new default stock, and added Distillation Slope and Vapor Pressure Constants to this table (each of which had been in separate tables).

ii. Table 7.1-4. This is a new table with equations for the height of the liquid heel and the vapor space under a landed floating roof, which may be used in estimating emissions from floating roof landings and tank cleanings.

iii. Table 7.1-5 This is a new table for LEL Values for Selected Compounds, which may be used in estimating tank cleaning emissions.

iv. Table 7.1-6. This is the table for Paint Solar Absorptance, in which the previous categories of “Good” and “Poor” have been relabeled “New” and “Aged.” In addition, a new category has been added labeled “Average,” which is the average of the values from the New and the Aged categories.

v. Table 7.1-7. Meteorological Data. Wind and atmospheric pressure have been added to this table. Wind had been in a separate table, and atmospheric pressure had not previously been included in the tabulation of meteorological data.

vi. Table 7.1-8. Rim Seals. Added emission factors for “tight fitting” rim seals.

vii. Table 7.1-12. Deck Fittings. Added emission factors for a flexible enclosure as a slotted guidepole control and a ladder sleeve as a ladder-guidepole control. Also added text to indicate which legs are for IFR-type decks and which are for EFR-type decks.

viii. Tables 7.1-20 and 7.1-21. New tables summarizing the equations needed for estimating emissions from tank cleaning events.

18) Sample Calculations.

a. All Examples. Revised the temperature calculations in accordance with changes made to these equations in the body of the document.

b. Example 4. Gasoline in an IFRT. Reworked to use Raoult’s Law to obtain partial speciation from liquid-phase concentrations, rather than a vapor profile from EPA’s SPECIATE database. Raoult’s Law is the approach presented in Section 7.1-4, Speciation Methodology, and thus seems the more appropriate approach to illustrate in the examples.

c. Example 5. Floating Roof Landing. Added this as a new example.

d. Example 6. Tank Cleaning. Added this as a new example.

Appendix A – Disposition of Each Equation

Documentation for equations.

New No.	Old No.	Change?	Reference
1-1	1-1	None	
1-2	1-2	None	
1-3	1-3	None	
1-4	1-4	None	
1-5	1-7	None. Moved the more general and accurate equation to precede the more approximate and case-specific equations.	
1-6	--	ΔT_V. New more general equation to calculate the vapor space temperature range, with H/D as a variable.	Appendix B
1-7	1-8	ΔT_V. Revised the coefficients to be based on a uniform assumption of 0.5 for the tank height-to-diameter ratio, and expressed these coefficients to one significant figure.	Appendix B
1-8	--	ΔT_V. New equation for the case of a partially insulated tank.	Appendix B
1-9	1-9	None	
--	1-10	ΔP_V. This was an alternative approximation that simplified the calculation of ΔP_V by avoiding the need to calculate P_{VX} and P_{VN} in Equation 1-9. However, it sometimes introduced significant error and is now unnecessary given computer tools for performing calculations. As it is no longer recommended, this equation has been moved to a new section for historical equations.	
1-10	1-11	None	
1-11	1-12	None	
1-12	1-5	Coefficients revised in expression for ΔT_V.	See new 1-7
1-13	1-6	None	
1-14	1-13	None	
1-15	1-14	None	
1-16	1-15	None	

Documentation for equations.

New No.	Old No.	Change?	Reference
1-17	1-16	None	
1-18	1-17	None	
1-19	1-18	None	
1-20	1-19	None	
1-21	1-20	None	
1-22	1-21	W_V. Replaced T_{LA} with T_V. In that W_V is the stock vapor density, the temperature in question is that of the vapor space. Earlier versions of the temperature equations had sometimes used liquid surface temperature as a surrogate for the vapor space temperature, but it would be more accurate to use the vapor space temperature. Expressions for vapor space temperature have been added as Equations 1-32 through 1-34.	See new 1-32 – 1-34
1-23	1-22	None	
1-24	1-23	None	
1-25	1-24	None	
1-26	1-25	None	
1-27	--	T_{LA}. New more general equation to calculate the liquid surface temperature, with H/D as a variable.	Appendix B
1-28	1-26	T_{LA}. Revised the coefficients to be based on a uniform assumption of 0.5 for the tank height-to-diameter ratio, and expressed these coefficients to one significant figure.	Appendix B
1-29	--	T_{LA}. New equation for the case of a partially insulated tank.	Appendix B
1-30	1-27	None	
1-31	1-28	T_B. Replaced the old equation, which did not account for insolation as a variable, with a new equation that does account for insolation as a variable.	Appendix B
1-32	--	T_V. New general equation to calculate the vapor space temperature, with H/D as a variable.	Appendix B

Documentation for equations.

New No.	Old No.	Change?	Reference
1-33	--	T_V. New simplified equation to calculate the vapor space temperature, with H/D set to 0.5.	Appendix B
1-34	--	T_V. New equation to calculate the vapor space temperature for the case of a partially insulated tank.	Appendix B
1-35	1-35	L_W. Replaced the expression for throughput as a function of full-tank turnovers with a variable, V_Q, which accounts for changes in liquid level.	See new 1-38
1-36	1-30	N. Changed calculation of net turnovers to be based on measured increases in liquid level, rather than on pump throughput, to more accurately account for scenarios in which pump-in and pump-out occur simultaneously. Calculation based on pump throughput is now shown as a fallback in the event that changes in liquid level are not known. Also, now accounts for low liquid level as well as high liquid level in determining the net working height of the tank. Old Equation 1-30 is now 60-3.	
1-37	1-30 1-31	Determination of N using the old approach based on pump throughput, but using net working height (H_{LX} - H_{LN}) rather than maximum liquid height (H_{LX}). That is, accounting for low liquid level as well as high liquid level. Old Equation 1-31 is now 60-4.	
1-38	--	V_Q. New equation to calculate the net throughput as a function of cumulative increases in liquid level.	Simple geometry
1-39	--	V_Q. Expression to determine throughput that accommodates the old approach based on pump throughput.	
1-40	1-36	None	
1-41	1-37	None	
--	1-29	L_W. This was an alternative approximation that simplified the calculation of L_W by assigning a default temperature to the vapor density term. This simplification is now unnecessary given computer tools for performing calculations. As it is no longer recommended, this equation has been moved to a new section for historical equations.	
--	1-32 1-33 1-34	These equations have been replaced by the text preceding 60-2.	

Documentation for equations.

New No.	Old No.	Change?	Reference
2-1 2-2	2-1	Broke the old equation into two equations to show that the sum of the rim seal, deck fitting and deck seam losses constitutes the standing loss.	
2-3	2-2	None	
2-4	2-3	None.	
2-5	--	T_{LA}. New general equation to calculate the liquid surface temperature for an internal floating-roof tank, with H/D as a variable.	Appendix B
2-6	--	T_{LA}. New simplified equation to calculate the liquid surface temperature for an internal floating-roof tank, with H/D set to 0.5.	Appendix B
2-7	--	T_{LA}. New equation to calculate the liquid surface temperature for a steel peripheral pontoon type external floating-roof tank.	Appendix B
2-8	--	T_B. New general equation to calculate the liquid bulk temperature for a steel peripheral pontoon type external floating-roof tank, with H/D as a variable.	Appendix B
2-9	--	T_B. New simplified equation to calculate the liquid bulk temperature for a steel peripheral pontoon type external floating-roof tank, with H/D set to 0.5.	Appendix B
2-10	--	T_{LA}. New equation to calculate the liquid surface temperature for a steel double-deck type external floating-roof tank.	Appendix B
2-11	--	T_B. New general equation to calculate the liquid bulk temperature for a steel double-deck type external floating-roof tank, with H/D as a variable.	Appendix B
2-12	--	T_B. New simplified equation to calculate the liquid bulk temperature for a steel double-deck type external floating-roof tank, with H/D set to 0.5.	Appendix B
2-13	2-5	None	
2-14	2-6	None	
2-15	2-7	None	
2-16	2-8	None	

Documentation for equations.

New No.	Old No.	Change?	Reference
2-17	--	None. This equation is in the old version, but not numbered.	
2-18	2-9	None	
2-19	2-4	None. This is for working loss from a floating-roof tank, but in the previous version it was inserted among equations for determining the components of standing loss. It has been moved to follow the standing loss calculations in the proposed revisions.	
2-20	--	*Q*. New equation to calculate the net throughput as a function of cumulative decreases in liquid level.	
3-1	2-10	None. Separated estimation of floating roof landing losses into a different section.	
3-2	2-11	None	
3-3	2-12	None	
3-4	2-13	None	
3-5	2-14	None	
3-6	2-15	Clarified that the temperature, T, is the temperature of the vapor space, T_V.	
3-7	2-16	None	
3-8	2-17	None	
3-9	2-18	None.	
3-10	2-19	None	
3-11	2-20	None	
3-12	2-21	None	
3-13	2-22	None	
3-14	2-23	None	
3-15	2-24	None	

Documentation for equations.

New No.	Old No.	Change?	Reference
3-16	--	New equation to calculate an upper limit on the filling loss based on the total mass of volatile material remaining in the bottom of the tank.	
3-17	2-25	Corrected "density" to read "concentration."	
3-18	2-26 2-27	Replaced old equation 2-26 with the more general expression in old equation 2-27. New equation 3-18 is the same as old equation 2-27. Thus effectively no change.	
3-19	2-28	None	
3-20	2-29	Edited text to reference revised equation numbers. No change in result.	
3-21	2-30	Substituted 1 for n_d, in that the number of days, n_d, is stated in the text as being set to 1. Thus effectively no change.	
--	2-31	Deleted the historic approximation for estimating K_e, and added a reference in the text to the more accurate expression in new equation 1-5.	See old 1-10
3-22	2-32	None	
4-1	--	New equation included for estimating emissions from tank cleaning events, which had not been addressed previously.	Development of these equations is presented in the text
4-2	--	ditto	ditto
4-3	--	ditto	ditto
4-4	--	ditto	ditto
4-5	--	ditto	ditto
4-6	--	ditto	ditto
4-7	--	ditto	ditto
4-8	--	ditto	ditto
4-9	--	ditto	ditto

Documentation for equations.

New No.	Old No.	Change?	Reference
4-10	--	ditto	ditto
4-11	--	ditto	ditto
4-12	--	ditto	ditto
4-13	--	ditto	ditto
5-1	--	New equation for estimating flashing losses based on the laboratory gas-to-oil ratio (GOR). Flashing losses had not been addressed previously.	measurement is in scf; apply unit conversion to obtain lb-moles; multiply by molecular weight to obtain pounds
6-1	3-1	None	
8-1	--	New equation included for estimating emissions from fully insulated fixed-roof tanks, which had not been addressed previously.	These equations express the assumption that all phases within a completely insulated tank are at the same temperature.
8-2	--	ditto	ditto
40-1	4-1	None	
40-2	4-2	None	
40-3	4-3	None	
40-4	4-4	None	
40-5	4-5	None	
40-6	4-6	None	
40-7	4-7	None	
40-8	4-8	None	

Documentation for equations.

New No.	Old No.	Change?	Reference
40-9	4-9	None	
60-1	1-10	ΔP_V. This was an alternative approximation that simplified the calculation of ΔP_V by avoiding the need to calculate P_{VX} and P_{VN} in Equation 1-9. However, it sometimes introduced significant error and is now unnecessary given computer tools for performing calculations. As it is no longer recommended, this equation has been moved to a new section for historical equations.	
60-2	1-29	No longer recommended as Equation 1-35 is preferred; this equation moved to new section for historical equations.	
60-3	1-30	Replaced by 1-36 and 1-37.	
60-4	1-31	Replaced by 1-36 and 1-37.	

Appendix B – Background on the Revised Temperature Equations

Discussion.

Prior Simplifications Now Unnecessary. The temperature equations that have been in AP-42 Chapter 7.1 were documented in API Publication 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. The original development of these equations took place prior to the proliferation of desktop computers, and thus there was a tendency at that time to make approximations and substitutions that would simplify the calculations. Given the present accessibility to computers, however, such simplifications are now unnecessary, and the equations in the proposed revisions to AP-42 have been revised to more accurately reflect the theoretical derivations.

For example, there was a development of a "gas space" (vapor space) temperature, alternatively labeled T_G or T_V in the documentation file, but this temperature was not used in the final equations. Rather, the final equations substituted the average liquid surface temperature, T_{LA}, for the vapor space temperature in equations such as the calculation of vapor density, W_V, in order to avoid the additional calculation for the vapor space temperature. The proposed revisions include a calculation of the vapor space temperature, T_V, and use of that temperature in the calculation of vapor density, W_V.

Significant Uncertainty in the Calculations. The storage tank temperature equations were derived from a theoretical energy transfer model that includes numerous parameters, some of which were assigned default values and some of which were retained as variables. For example, angle of the sun, reflectivity of the surrounding ground surfaces, average liquid level, and insulation value of a given floating roof design were all assigned default values, whereas ambient temperature, liquid bulk temperature, average incident solar radiation (insolation), and reflectivity of the tank exterior surfaces were retained as variables in the final equations.

The resulting equations have significant uncertainty when applied to a specific scenario, in part because the default values assigned to certain parameters may not be representative for the given scenario, and in part because the parameters retained as variables are assigned average values when the actual values may vary greatly over time (e.g., ambient temperature). Given the uncertainty in this approach to calculating storage tank temperatures, the prior practice of expressing the coefficients in the equations to two significant figures was deemed inappropriate and potentially misleading, and thus the coefficients in the revised equations are expressed to one significant figure.

Inconsistencies in the Prior Equations. Review of the earlier documentation also revealed multiple inconsistencies, such as a default value of 0.45 being assigned to the tank height-to-diameter ratio in one instance and a value of 2.0 in another instance. The revised equations include one set of equations with the height-to-diameter ratio retained as a variable and another set of equations with a default value of 0.5 assigned to the height-to-diameter ratio. While the dimensions of storage tanks in the petroleum industry vary dramatically, many tanks are 40 or 48 feet tall and 90 to 120 feet in diameter.

Illustrations of the impact of the changes in the defaults equations for the average liquid surface temperature, T_{LA}, and the range in vapor space temperature, ΔT_V, are shown in the table below.

Comparison of Estimated Emissions -- Prior Defaults versus Revised Defaults

Calculating the average liquid surface temperature, T_{LA}, and the range in vapor space temperature, ΔT_V, from default equations.

Cases illustrate low and high throughputs and low and high temperatures.

Assumptions for these examples:

Location: **New Orleans, LA**

Average Ambient Temperature:	**68.0**	deg F
Avg Ambient Temperature Range:	**19.1**	deg F
Average Insolation:	**1444**	Btu/(ft^2 day)

Tank Type: **FRT(no floating roof)**

Insulated? **No**

Paint: **white**

Diameter: **40** feet

Product: **#2 Fuel Oil**

			Calculated Using Prior Defaults (paint in good condition)					Calculated Using Revised Defaults (paint in new condition)					Calculated Using Revised Defaults (paint in average condition)				
Case	Throughput (gallons)	Liquid Bulk Temp (deg F)	Liquid Surface Temp (deg F)	Avg TVP (psia)	Estimated Losses This Period Standing	Estimated Losses This Period Working	Total Emissions (lbs)	Liquid Surface Temp (deg F)	Avg TVP (psia)	Estimated Losses This Period Standing	Estimated Losses This Period Working	Total Emissions (lbs)	Liquid Surface Temp (deg F)	Avg TVP (psia)	Estimated Losses This Period Standing	Estimated Losses This Period Working	Total Emissions (lbs)
1	1,297,800	60.0	65.4	0.008	70	31	**100**	64.4	0.007	59	30	**89**	65.0	0.008	69	30	**99**
2	12,978,000	60.0	65.4	0.008	70	308	**377**	64.4	0.007	59	298	**357**	65.0	0.008	69	303	**371**
3	1,297,800	120.0	99.0	0.021	175	83	**258**	100.4	0.022	156	86	**242**	101.0	0.023	181	87	**268**
4	12,978,000	120.0	99.0	0.021	175	834	**1,009**	100.4	0.022	156	859	**1,015**	101.0	0.023	181	871	**1,052**

The table that follows illustrates the sensitivity of estimated emissions to the height-to-diameter ratio of the tank, using the same example as described above but using varying values for the height-to-diameter ratio in the temperature equations. The relatively low sensitivity of estimated emissions to the height-to-diameter ratio has historically been cited to justify use of a default value for this parameter. However, both height and diameter of the tank are values that are generally known, and thus inclusion of the height-to-diameter ratio as a variable does not add significant burden when the calculations are being performed by a computer program.

H/D = 0.2

Case	Throughput (gallons)	Liquid Bulk Temp (deg F)	Liquid Surface Temp (deg F)	Avg TVP (psia)	Estimated Losses This Period: Standing	Estimated Losses This Period: Working	Total Emissions (lbs)	% of value for H/D = 0.5
1	1,297,800	60.0	63.6	0.007	58	29	**87**	98%
2	12,978,000	60.0	63.6	0.007	58	290	**348**	97%
3	1,297,800	120.0	105.6	0.026	179	99	**278**	115%
4	12,978,000	120.0	105.6	0.026	179	994	**1,172**	115%

H/D = 0.35

Case	Throughput (gallons)	Liquid Bulk Temp (deg F)	Liquid Surface Temp (deg F)	Avg TVP (psia)	Estimated Losses This Period: Standing	Estimated Losses This Period: Working	Total Emissions (lbs)	% of value for H/D = 0.5
1	1,297,800	60.0	64.4	0.007	59	30	**89**	100%
2	12,978,000	60.0	64.4	0.007	59	298	**357**	100%
3	1,297,800	120.0	100.4	0.022	156	86	**242**	100%
4	12,978,000	120.0	100.4	0.022	156	859	**1,015**	100%

H/D = 0.5

Case	Throughput (gallons)	Liquid Bulk Temp (deg F)	Liquid Surface Temp (deg F)	Avg TVP (psia)	Estimated Losses This Period: Standing	Estimated Losses This Period: Working	Total Emissions (lbs)
1	1,297,800	60.0	64.4	0.007	59	30	**89**
2	12,978,000	60.0	64.4	0.007	59	298	**357**
3	1,297,800	120.0	100.4	0.022	156	86	**242**
4	12,978,000	120.0	100.4	0.022	156	859	**1,015**

H/D = 0.75

Case	Throughput (gallons)	Liquid Bulk Temp (deg F)	Liquid Surface Temp (deg F)	Avg TVP (psia)	Estimated Losses This Period: Standing	Estimated Losses This Period: Working	Total Emissions (lbs)	% of value for H/D = 0.5
1	1,297,800	60.0	64.2	0.007	65	30	**95**	107%
2	12,978,000	60.0	64.2	0.007	65	295	**361**	101%
3	1,297,800	120.0	100.2	0.022	176	86	**262**	108%
4	12,978,000	120.0	100.2	0.022	176	861	**1,037**	102%

H/D = 1.0

Case	Throughput (gallons)	Liquid Bulk Temp (deg F)	Liquid Surface Temp (deg F)	Avg TVP (psia)	Estimated Losses This Period: Standing	Estimated Losses This Period: Working	Total Emissions (lbs)	% of value for H/D = 0.5
1	1,297,800	60.0	64.2	0.007	66	30	**95**	107%
2	12,978,000	60.0	64.2	0.007	66	295	**361**	101%
3	1,297,800	120.0	100.2	0.022	176	86	**262**	108%
4	12,978,000	120.0	100.2	0.022	176	861	**1,037**	102%

H/D = 2.0

Case	Throughput (gallons)	Liquid Bulk Temp (deg F)	Liquid Surface Temp (deg F)	Avg TVP (psia)	Estimated Losses This Period: Standing	Estimated Losses This Period: Working	Total Emissions (lbs)	% of value for H/D = 0.5
1	1,297,800	60.0	64.2	0.007	63	29	**93**	105%
2	12,978,000	60.0	64.2	0.007	63	295	**358**	100%
3	1,297,800	120.0	100.2	0.022	172	87	**259**	107%
4	12,978,000	120.0	100.2	0.022	172	870	**1,042**	103%

Accounting for Insolation in Liquid Bulk Temperature. The prior equation for calculating the liquid bulk temperature, T_B, from an assumption of equilibrium with ambient conditions was not derived from the theoretical energy transfer model, but rather was derived from limited empirical data. The resulting expression did not account for geographical differences in average insolation, and thus gave the same increase above ambient temperature for Nome, AK as for Phoenix, AZ.

The table below shows a comparison of the increase in liquid bulk temperature, T_B, above average ambient temperature, T_{AA}, estimated by both the prior and the revised equations for a tank in equilibrium with ambient conditions, for different scenarios of paint color/condition and insolation. It's evident that the difference between the two approaches is generally a fraction of a degree, but the revised equation is more rational in that it accounts for insolation.

Comparison of the estimated increase in liquid bulk temperature, T_B, above average ambient temperature, T_{AA}, for a tank in equilibrium with ambient conditions.

Tank color/condition:	**White/New**	Temperature increase (F) above ambient, for the given equation:	
		prior	**revised**
α	I	+ 6α – 1	+ 0.003αI
0.17	838	0.02	0.43
0.17	1370	0.02	0.70
0.17	1872	0.02	0.95

Tank color/condition:	**White/Average**	Temperature increase (F) above ambient, for the given equation:	
		prior	**revised**
α	I	+ 6α – 1	+ 0.003αI
0.25	838	0.50	0.63
0.25	1370	0.50	1.03
0.25	1872	0.50	1.40

Tank color/condition:	**Light Gray/Average**	Temperature increase (F) above ambient, for the given equation:	
		prior	**revised**
α	I	+ 6α – 1	+ 0.003αI
0.58	838	2.48	1.46
0.58	1370	2.48	2.38
0.58	1872	2.48	3.26

Tank color/condition:	**Dark Green/Average**	Temperature increase (F) above ambient, for the given equation:	
		prior	**revised**
α	I	+ 6α – 1	+ 0.003αI
0.9	838	4.40	2.26
0.9	1370	4.40	3.70
0.9	1872	4.40	5.05

Accounting for Tank Type in the Calculation of Tank Temperatures. AP-42 Chapter 7.1 has historically used the equation developed for calculating the liquid temperatures of fixed-roof tanks to also calculate the liquid temperatures for floating-roof tanks. There are differences, however, in the energy transfer models for each tank type. The fixed-roof tank has a vapor space beneath the fixed-roof and an open liquid surface within the tank. An internal floating-roof tank has a similar vapor space beneath the fixed-roof, but has a floating roof covering the liquid surface. An external floating-roof tank does not have a fixed roof and an enclosed vapor space, but rather has solar radiation directly incident upon the floating roof. The proposed revisions to AP-42 introduce separate equations to calculate liquid temperatures for each tank type, accounting for the heat conductance characteristics of floating roofs and for the absence of an enclosed vapor space for external floating-roof tanks.

The table below shows a comparison of the increase in liquid bulk temperature, T_B, above average ambient temperature, T_{AA}, estimated by both the prior and the revised equations for both fixed-roof tanks (FRTs) and external floating-roof tanks (EFRTs), assuming equilibrium with ambient conditions, for different scenarios of paint color/condition and insolation.

Comparison of the estimated increase in liquid bulk temperature, T_B, above average ambient temperature, T_{AA}, for an EFRT vs an FRT in equilibrium with ambient conditions.

Tank color/condition:	**White/New**	Temperature increase (F) above ambient, for the given equation:	
		FRT	**EFRT**
α	I	+ 0.003αI	+ 0.007αI
0.17	838	0.43	1.00
0.17	1370	0.70	1.63
0.17	1872	0.95	2.23
Tank color/condition:	**White/Average**	Temperature increase (F) above ambient, for the given equation:	
		FRT	**EFRT**
α	I	+ 0.003αI	+ 0.007αI
0.25	838	0.63	1.47
0.25	1370	1.03	2.40
0.25	1872	1.40	3.28
Tank color/condition:	**Light Gray/Average**	Temperature increase (F) above ambient, for the given equation:	
		FRT	**EFRT**
α	I	+ 0.003αI	+ 0.007αI
0.58	838	1.46	3.40
0.58	1370	2.38	5.56
0.58	1872	3.26	7.60
Tank color/condition:	**Dark Green/Average**	Temperature increase (F) above ambient, for the given equation:	
		FRT	**EFRT**
α	I	+ 0.003αI	+ 0.007αI
0.9	838	2.26	5.28
0.9	1370	3.70	8.63
0.9	1872	5.05	11.79

Partially and Fully Insulated Storage Tanks. AP-42 Chapter 7.1 has historically excluded insulated tanks from the scope of the document, but the proposed revisions add guidance for insulated tanks. This guidance distinguishes between a fully insulated tank (being a tank with effective insulation covering both the roof and the shell), and a partially insulated tank (being a tank having an insulated shell but an uninsulated roof).

The proposed revisions indicate that for a fully insulated tank an assumption may be made of the liquid surface temperature being equal to the liquid bulk temperature, in that there is minimal heat loss through the roof or shell of the tank. It may further assumed that there is no generation of breathing loss from the ambient diurnal temperature cycle in that there is minimal heat transfer through the roof and shell of the tank. However, equations are provided to estimate breathing losses driven by temperature cycles in the heating of the liquid stock in a fully insulated tank.

The proposed revisions indicate that a partially insulated tank may be modeled as an uninsulated tank in that significant heat transfer will take place through the tank roof. Alternatively, equations derived from the theoretical energy transfer model are provided for more accurate modeling of partially insulated tanks.

Derivation of Equations.

Symbol	Description	Units
c_B	conductance of bottom	Btu/(ft^2 hr °F)
c_E	conductance of EFR and liquid surface	Btu/(ft^2 hr °F)
c_F	conductance of floating roof	Btu/(ft^2 hr °F)
c_I	conductance of IFR and liquid surface	Btu/(ft^2 hr °F)
c_L	conductance of free liquid surface	Btu/(ft^2 hr °F)
c_{RV}	conductance of roof in vapor space	Btu/(ft^2 hr °F)
c_{SL}	conductance of shell in liquid space	Btu/(ft^2 hr °F)
c_{SV}	conductance of shell in vapor space	Btu/(ft^2 hr °F)
D	tank diameter	ft
f	portion of insolation transferred to EFRT stock	dimensionless
H_s	tank shell height	ft
I	insolation	Btu/(ft^2 day)
I_H	hourly insolation factor	Btu/(ft^2 hr)
T_{AA}	average daily ambient temperature	°R
T_B	average liquid bulk temperature	°R
T_B	equilibrium liquid bulk temperature	°R
T_{LA}	average daily liquid surface temperature	°R
T_{LN}	average daily minimum liquid surface temperature	°R
T_{LX}	average daily maximum liquid surface temperature	°R
T_V	average vapor temperature	°R
T_V	equilibrium vapor temperature	°R
A	solar absorptance	dimensionless
α_R	solar absorptance (roof)	dimensionless
α_S	solar absorptance (shell)	dimensionless
ΔT_V	average daily vapor temperature range	°R

Temperature of the Fixed-Roof Tank Vapor Space at Equilibrium, T_V

An equation for calculating the temperature of the vapor space, T_V, is new to AP-42. It is used in Equation 1-22 for calculation of the stock vapor density, W_V, which previously used the average liquid surface temperature, T_{LA}, as an approximation of the vapor space temperature.

General equation:

$T_V = [2T_{AA}\, c_{SV}\, H_s/D + T_{AA}\, c_{RV} + T_B\, c_L + (0.5\alpha_R I + 0.309\, \alpha_S I\, H_s/D)/24]/[2\, c_{SV}\, H_s/D + c_L + c_{RV}]$

Rearranging:

$T_V = [(2\, c_{SV}\, H_s/D + c_{RV})\, T_{AA} + c_L\, T_B + (0.5/24)\, \alpha_R I + (0.309/24)\, (H_s/D)\, \alpha_S I] / [2\, c_{SV}\, H_s/D + c_L + c_{RV}]$

Default values:

c_{SV} = 1.1 tank shell enclosing the vapor space (single layer of steel, uninsulated)

c_{RV} = 1.1 tank (fixed) roof enclosing the vapor space (single layer of steel, uninsulated)

c_L = 0.8 FRT (free liquid surface, no floating roof)

Fixed-Roof Tank – uninsulated:

The average vapor temperature, T_V, may be calculated using the following equation:

$\mathbf{T_V} = [(2.2\, H_s/D + 1.1)\, \mathbf{T_{AA}} + 0.8\, \mathbf{T_B} + 0.021\, \boldsymbol{\alpha_R} \mathbf{I} + 0.013\, (H_s/D)\, \boldsymbol{\alpha_S} \mathbf{I}] / [2.2\, H_s/D + 1.9]$ (1-32)

API assigns a default value of $H_s/D = 0.5$ and an assumption of $\alpha_R = \alpha_S$, resulting in the simplified equation shown below:

$\mathbf{T_V} = 0.7\, \mathbf{T_{AA}} + 0.3\, \mathbf{T_B} + 0.009\, \boldsymbol{\alpha}\, \mathbf{I}$ (1-33)

Fixed-Roof Tank – partially insulated (insulated shell, uninsulated roof):

When the shell is insulated, the temperature equations are independent of H_s/D.

$\mathbf{T_V} = 0.6\, \mathbf{T_{AA}} + 0.4\, \mathbf{T_B} + 0.01\, \boldsymbol{\alpha_R}\, \mathbf{I}$ (1-34)

Fixed-Roof Tank – fully insulated (insulated shell, insulated roof):

When the tank shell and roof are fully insulated, the temperatures of the vapor space and the liquid surface are taken as equal to the temperature of the bulk liquid.

$\mathbf{T_V} = \mathbf{T_B}$

Temperature Range of the Fixed-Roof Tank Vapor Space at Equilibrium, ΔT_V

General equation:

$\Delta T_V = (T_{AX} - T_{AN})(1 - c_L/M) + 2I_H /M$

where:

$I_H = (0.5\alpha_R I + 0.309\ \alpha_S I\ H_s/D)/24$

$M = 2\ c_{SV}\ H_s/D + c_{RV} + c_L$

and thus:

$\Delta T_V = [1 - c_L / (2\ c_{SV}\ H_s/D + c_L + c_{RV})]\ (T_{AX} - T_{AN}) + 2\ [(0.5/24)\ \alpha_R I + (0.309/24)\ (H_s/D)\ \alpha_S I] / (2\ c_{SV}\ H_s/D + c_L + c_{RV})$

Default values given at T_V above.

Fixed-Roof Tank – uninsulated:

$\mathbf{\Delta T_V} = [1 - 0.8 / (2.2\ H_s/D + 1.9)]\ (\mathbf{T_{AX}} - \mathbf{T_{AN}}) + [0.042\ \boldsymbol{\alpha_R}\mathbf{I} + 0.026\ (H_s/D)\ \boldsymbol{\alpha_S}\mathbf{I}] / (2.2\ H_s/D + 1.9)$ (1-6)

For default $H_s/D = 0.5$, when $\alpha_R = \alpha_S$:

$\mathbf{\Delta T_V} = 0.7\ (\mathbf{T_{AX}} - \mathbf{T_{AN}}) + 0.02\ \boldsymbol{\alpha}\ \mathbf{I}$ (1-7)

Fixed-Roof Tank – partially insulated (insulated shell, uninsulated roof):

When the shell is insulated, the temperature equations are independent of H_s/D.

$\mathbf{\Delta T_V} = 0.6\ (\mathbf{T_{AX}} - \mathbf{T_{AN}}) + 0.02\ \boldsymbol{\alpha_R}\ \mathbf{I}$ (1-8)

Fixed-Roof Tank – fully insulated (insulated shell, insulated roof):

When the tank shell and roof are fully insulated, the temperatures of the vapor space and the liquid surface are taken as equal to the temperature of the bulk liquid. When the bulk liquid is maintained at a constant temperature:

$\mathbf{\Delta T_V} = 0$

Note, however, that when there are cycles to the temperature of the bulk liquid, these heating cycles will result in corresponding cycles in the temperature of the vapor space.

Temperature of the Bulk Liquid at Equilibrium, T_B

Fixed-Roof Tanks and Internal Floating-Roof Tanks

$T_B = T_{AA} + (c_L\ D\ I_H + KM)/(JM - c_L\ \ 2\ D)$

where:

$I_H = (0.5\alpha_R I + 0.309\ \alpha_S I\ H_s/D)/24$

$K = 0.0257\alpha_S I H_s$

$M = 2\ c_{SV}\ H_s/D + c_{RV} + c_L$

$J = 2c_{SL}\ H_s + c_B\ D + c_L\ D$

and thus:

$$T_B = T_{AA} + \{c_L\ D\ [(0.5/24)\ \alpha_R I + (0.309/24)\ (H_s/D)\ \alpha_S I] + [(0.0257\ \alpha_S I H_s)(2\ c_{SV}\ H_s/D + c_L\ + c_{RV})]\}\ /\ [(2c_{SL}\ H_s + c_B\ D + c_L\ D)(2\ c_{SV}\ H_s/D + c_L\ + c_{RV}) - c_L^2\ D]$$

Default values given at T_V except for:

c_{SL}	=	4.5	tank shell enclosing the stored liquid (single layer of steel, uninsulated)
c_B	=	2	tank bottom beneath the stored liquid (single layer of steel, uninsulated)

Note: For IFRTs, use c_I rather than c_L. where $(1/c_I) = (1/2c_L + 1/c_F)$ and $1/c_F$ is the thermal resistance of the floating roof.

Fixed-Roof Tank and Internal Floating-Roof Tank – uninsulated:

For tanks with a fixed roof, the heat gain to the bulk liquid from insolation is almost entirely through the tank shell, and thus the relationship of liquid bulk temperature to ambient temperature is not sensitive to H_s/D.

$$\mathbf{T_B} = \mathbf{T_{AA}} + 0.003\ \boldsymbol{\alpha_S}\ \mathbf{I} \qquad (1\text{-}31)$$

Insulated Tanks:

When the tank is insulated, the liquid bulk temperature is likely not in equilibrium with ambient conditions. In such cases, the actual temperature of the bulk liquid should be used.

* *

External Floating-Roof Tanks

$T_B = T_{AA} + [0.785\ f\ \alpha_R I + 0.485\ (H_s/D)\ \alpha_S I]/(12\pi\ c_{SL}\ H_s/D + 6\pi\ c_B\ + 6\pi\ c_E)$

Default values given at T_B except for:

f	=	0.9	EFRT (steel pontoon deck with single-deck center area)
f	=	0.5	EFRT (steel double-deck)
c_E	=	1	EFRT (steel pontoon deck with single-deck center area, exposed to wind)
c_E	=	0.4	EFRT (steel double-deck, exposed to wind)

External Floating-Roof Tank – steel peripheral pontoon deck (single deck center area):

$$\mathbf{T_B} = \mathbf{T_{AA}} + [0.71\ \boldsymbol{\alpha_R}\mathbf{I} + 0.485\ (H_s/D)\ \boldsymbol{\alpha_S}\mathbf{I}]\ /\ (170\ H_s/D + 57) \qquad (2\text{-}8)$$

For default $H_s/D = 0.5$, when $\alpha_R = \alpha_S$:

$$\mathbf{T_B} = \mathbf{T_{AA}} + 0.007\ \boldsymbol{\alpha}\ \mathbf{I} \qquad (2\text{-}9)$$

External Floating-Roof Tank – steel double deck:

$$\mathbf{T_B} = \mathbf{T_{AA}} + [0.39\ \boldsymbol{\alpha_R}\mathbf{I} + 0.485\ (H_s/D)\ \boldsymbol{\alpha_S}\mathbf{I}]\ /\ (170\ H_s/D + 45) \quad (2\text{-}11)$$

For default $H_s/D = 0.5$, when $\alpha_R = \alpha_S$:

$$\mathbf{T_B} = \mathbf{T_{AA}} + 0.005\ \boldsymbol{\alpha}\ \mathbf{I} \quad (2\text{-}12)$$

Temperature of Fixed-Roof Tank Liquid Surface at Equilibrium, T_L

Average Liquid Surface Temperature, T_{LA}

$T_{LA} = (0.5 - c_L /2M)\ T_{AA} + (0.5 + c_L /2M)\ T_B + I_H /(2M)$

where:

$M = (2\ c_{SV}\ H_s/D + c_{RV} + c_L)$

$I_H = [(0.5\alpha_R I + 0.309\ \alpha_S I\ H_s/D)/24]$

and thus:

$T_{LA} = \{0.5 - c_L /[2(2\ c_{SV}\ H_s/D + c_{RV} + c_L)]\}\ T_{AA} + \{0.5 + c_L /[2(2\ c_{SV}\ H_s/D + c_{RV} + c_L)]\}\ T_B + [(0.5/24)\alpha_R I + (0.309/24)\ (H_s/D)\ \alpha_S I] / [2(2\ c_{SV}\ H_s/D + c_{RV} + c_L)]$

Average Liquid Surface Temperature, T_{LA}

Fixed-Roof Tank – uninsulated:

$$\mathbf{T_{LA}} = \{0.5 - 0.8 / (4.4\ H_s/D + 3.8)\}\ \mathbf{T_{AA}} + \{0.5 + 0.8 / (4.4\ H_s/D + 3.8)\}\ \mathbf{T_B} + [0.021\ \boldsymbol{\alpha_R}\mathbf{I} + 0.013\ (H_s/D)\ \boldsymbol{\alpha_S}\mathbf{I}] / (4.4\ H_s/D + 3.8) \quad (1\text{-}27)$$

For default $H_s/D = 0.5$, when $\alpha_R = \alpha_S$:

$$\mathbf{T_{LA}} = 0.4\ \mathbf{T_{AA}} + 0.6\ \mathbf{T_B} + 0.005\ \boldsymbol{\alpha}\ \mathbf{I} \quad (1\text{-}28)$$

Fixed-Roof Tank – partially insulated (insulated shell, uninsulated roof):

When the shell is insulated, the temperature equations are independent of H_s/D.

$$\mathbf{T_{LA}} = 0.3\ \mathbf{T_{AA}} + 0.7\ \mathbf{T_B} + 0.005\ \boldsymbol{\alpha_R}\ \mathbf{I} \quad (1\text{-}29)$$

Fixed-Roof Tank – fully insulated (insulated shell, insulated roof):

When the tank shell and roof are fully insulated, the temperatures of the vapor space and the liquid surface are taken as equal to the temperature of the bulk liquid.

$\mathbf{T_{LA}} = \mathbf{T_B}$

Average Temperature of External Floating-Roof Tank Liquid Surface at Equilibrium, T_{LA}

External Floating-Roof Tanks

$T_{LA} = [c_F\, T_{AA} + 2c_L\, T_B + (f/24)\alpha_R I] / (2c_L + c_F)$

Default values given at T_V and T_{Befr} except for:

c_F = 3 EFRT (steel pontoon deck with single-deck center area, exposed to wind)

c_F = 0.6 EFRT (steel double-deck, exposed to wind)

Note: For floating roofs, the effective liquid surface conductance (i.e., between the bulk liquid and the vapor space) is a function of the free liquid surface conductance c_L and the floating roof deck conductance c_F.

The effective liquid surface conductance c_I for an IFRT or c_E for an EFRT relates to the free liquid surface conductance c_L and the floating roof deck conductance c_F as follows:

$1/c_I = 1/(2c_L) + 1/c_F$

$1/c_E = 1/(2c_L) + 1/c_F$

The EFRT model for T_{LA} is independent of H_s/D for a given value of T_B, in that it is a function of T_{AA} rather than T_V.

External Floating-Roof Tank – steel peripheral pontoon deck (single deck center area):

$$\mathbf{T_{LA}} = 0.7\, \mathbf{T_{AA}} + 0.3\, \mathbf{T_B} + 0.008\, \boldsymbol{\alpha_R}\mathbf{I} \quad (2\text{-}7)$$

External Floating-Roof Tank – steel double deck:

$$\mathbf{T_{LA}} = 0.3\, \mathbf{T_{AA}} + 0.7\, \mathbf{T_B} + 0.009\, \boldsymbol{\alpha_R}\mathbf{I} \quad (2\text{-}10)$$

Average Temperature of Internal Floating-Roof Tank Liquid Surface at Equilibrium, T_{LA}

Internal Floating-Roof Tanks

$T_{LA} = [c_F\, T_V + 2c_L\, T_B] / (2c_L + c_F)$

where:

$T_V = [(2\, c_{SV}\, H_s/D + c_{RV})\, T_{AA} + c_I\, T_B + (0.5/24)\, \alpha_R I + (0.309/24)\, (H_s/D)\, \alpha_S I] / [2\, c_{SV}\, H_s/D + c_I + c_{RV}]$

and thus:

$T_{LA} = (\{c_F\, [(2\, c_{SV}\, H_s/D + c_{RV})\, T_{AA} + c_I\, T_B + (0.5/24)\, \alpha_R I + (0.309/24)\, (H_s/D)\, \alpha_S I] / [2\, c_{SV}\, H_s/D + c_I + c_{RV}]\} + 2c_L\, T_B) / (2c_L + c_F)$

Rearranging:

$T_{LA} = \{c_F\, (2\, c_{SV}\, H_s/D + c_{RV})\, T_{AA} + [(c_F\, c_I) + 2c_L\, (2\, c_{SV}\, H_s/D + c_I + c_{RV})]\, T_B + c_F\, (0.5/24)\, \alpha_R I + c_F\, (0.309/24)\, (H_s/D)\, \alpha_S I\} / [2\, c_{SV}\, H_s/D + c_I + c_{RV})\, (2c_L + c_F)]$

Default values given at T_V and T_{Befr} except for:

c_F = 0.5 IFRT (aluminum skin-and-pontoon deck)

c_F = 1.5 IFRT (steel pan deck)

c_F = 1.3 Domed EFRT (steel pontoon deck with single-deck center area)

c_F = 0.5 Domed EFRT (steel double-deck)

The actual conductance of a floating roof is generally not known. The default values given above for aluminum skin-and-pontoon decks and steel double decks assume an uninterrupted vapor space between the top and bottom layers of metal, but in reality there are bulkheads and other attachment points that act as thermal bridges between these metal layers. The case of a steel pan is based on the entire deck being a single layer of steel, with no enclosed flotation compartments. The case of a steel pontoon deck with a single-deck center area accounts for some of the deck having a vapor space within enclosed compartments and some not, and thus represents an intermediate case. Therefore the steel pontoon deck has been selected to represent IFRs in general.

Internal Floating-Roof Tank:

$\mathbf{T_{LA}} = \{[2.86\, (H_s/D) + 1.43]\, \mathbf{T_{AA}} + [0.91 + 3.52\, (H_s/D) + 2.88]\, \mathbf{T_B} + 0.027\, \boldsymbol{\alpha_R I} + 0.017\, (H_s/D)\, \boldsymbol{\alpha_S I}\} / [6.38\, (H_s/D) + 5.22]$

$$\mathbf{T_{LA}} = \{[2.86\, (H_s/D) + 1.43]\, \mathbf{T_{AA}} + [3.52\, (H_s/D) + 3.79]\, \mathbf{T_B} + 0.027\, \boldsymbol{\alpha_R I} + 0.017\, (H_s/D)\, \boldsymbol{\alpha_S I}\} / [6.38\, (H_s/D) + 5.22] \quad (2\text{-}5)$$

For default $H_s/D = 0.5$, when $\alpha_R = \alpha_S$:

$$\mathbf{T_{LA}} = 0.3\, \mathbf{T_{AA}} + 0.7\, \mathbf{T_B} + 0.004\, \boldsymbol{\alpha\, I} \quad (2\text{-}6)$$