

# Evaporative Loss from Storage Tank Floating Roof Landings

TECHNICAL REPORT 2567  
APRIL 2005



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# Evaporative Loss from Storage Tank Floating Roof Landings

## Measurement Coordination

TECHNICAL REPORT 2567  
APRIL 2005

Prepared by:

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## FOREWORD

The methodologies presented in this report were presented previously in a January 23, 2002, report, *Tentative Method for Determining Storage Tank Evaporative Losses from Floating Roof Landings*, prepared for API by Robert L. Ferry of The TGB Partnership. The purpose of this revision is to address a scenario that was not addressed in the earlier report. The earlier report addressed storage tanks that retain a heel of stock liquid across the entire bottom of the tank when the floating roof is landed, and storage tanks that are drained dry. This revision addresses the intermediate case of a partial liquid heel, in which pools of stock liquid remain in the tank (and thus it is not drained dry), but the free standing liquid does not cover the entire bottom of the tank. There have been no changes to the equations or factors presented in the earlier report, other than the addition of the case for a partial liquid heel.

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Suggested revisions are invited and should be submitted to API, Standards department, 1220 L Street, NW, Washington, DC 20005, [standards@api.org](mailto:standards@api.org).

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# Evaporative Loss from Storage Tank Floating Roof Landings

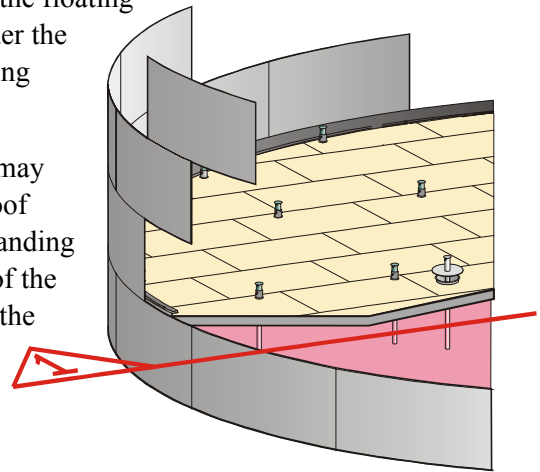
## 1. EXECUTIVE SUMMARY

### 1.1 Statement of Purpose

The purpose of this study was to investigate storage tank emissions that may result from landing and subsequently refloating a floating roof. The existing emission factors for floating-roof tanks<sup>1,2</sup> are based on the assumption that the floating roof is continuously floating on the stored stock liquid. Additional emissions may occur, however, if the tank is emptied such that the floating roof is no longer floating.

When the liquid level approaches the bottom of the tank, the floating roof lands on deck legs or other supports which prevent it from dropping any further as the stock liquid continues to be removed. Further withdrawal of stock liquid could then potentially form a partial vacuum beneath the landed floating roof. If the receding liquid were to create an excessive partial vacuum, the floating roof could collapse. To avoid this condition, a vacuum-breaker vent on the floating roof opens automatically as the floating roof lands (see Figure 1 on page 6). The vapor space created under the floating roof is thereby freely vented to the space above the floating roof.

Vapor loss (and the corresponding emissions to the atmosphere) may occur while the tank remains nominally empty and the floating roof continues to stand idle in this landed condition (see Figure 2 – Standing Idle Loss). Additional emissions may occur during the refilling of the tank, as the vapor space beneath the floating roof is displaced by the incoming stock liquid (see Figure 3 – Filling Loss). This study sought to quantify these floating-roof landing loss emissions.



### 1.2 Summary of the Investigations

Part I of this study proposed a methodology for estimating floating-roof landing losses for tanks storing refined products. Steps pursued in the development of this methodology included a literature search,<sup>1-14</sup> a survey of manufacturers and owners of petroleum storage tanks, computer modeling, and analyses of available emissions data from fixed-roof tank breather vents and from barge loading operations. The results of Part I were presented in the report, *Determining Product Evaporation from Tank Turnovers*,<sup>15</sup> October 1, 1997, prepared for API by Robert L. Ferry and J. Randolph Kissell of The TGB Partnership (TGB).

Data collection for Part II of the study involved field tests that were conducted in 1998 and 1999. Data were obtained from four tanks, each representing a different combination of tank construction and type of stock liquid. It was not economically feasible to test a sufficient number of tanks to empirically determine emission factors for floating-roof landing losses, given the spectrum of construction configurations and storage conditions found in the industry. Furthermore, limitations on accessibility to the space under the floating roof impose constraints on the field methods used. These limitations were found to impact the absolute accuracy of the data gathered.

While it was recognized that the testing of a single tank is insufficient for determining a typical value for the entire population of similar tanks, and that the data gathered should be interpreted as relative indicators rather than as absolute measures, it was expected that comparison of the data from each of the test tanks would indicate relative trends for the different tank configurations. The results of these field tests were presented in the report, *Determining Product Evaporation from Tank Turnovers, Part II - Tank Testing*,<sup>16</sup> May 1999, prepared for API by Sue Sung and Yousheng Zeng of Trinity Consultants.

Part II of the study also included a review by TGB of the methodology proposed in Part I, in light of the field test results and other available data. This review specifically considered the following:

- a. whether wind effects should be included in the model,
- b. extension of the model to include crude oil, and
- c. reasonableness of the model in light of the relative trends exhibited in the field data.

Part III of the study incorporated the results of Parts I and II into a revised model for estimating floating-roof landing losses. This revised model was presented in the January 23, 2002 report, *Tentative Method for Determining Storage Tank Evaporative Losses from Floating Roof Landings*,<sup>17</sup> prepared for API by Rob Ferry of TGB.

API sponsored an additional field study in 2003 that sought to overcome the testing difficulties experienced in the earlier field work. The first step of this study was to develop field and laboratory protocols for measuring the concentration of vapors displaced from under a landed floating roof during the refilling process. These protocols were then applied to obtain data from three internal floating-roof tanks, each of which was in gasoline service. This 2003 field study provided spot validation of the 60% vapor saturation value proposed in the 1/23/02 TGB Report for internal floating-roof tanks with a full liquid heel (see Table 1). The results of the 2003 study were presented in the January 28, 2004 report, *Floating Roof Landing Loss: Field Study of Saturation Factors for Refilling of Internal Floating-Roof Tanks*,<sup>18</sup> prepared for API by Rob Ferry of TGB.

In addition to spot validation of the full liquid heel case, the 2003 study collected samples from tanks for which the liquid heel did not extend across the entire bottom of the tank. The free-standing liquid in these partial liquid heel cases was confined to the area in or near the sump. This case of a partial liquid heel was not addressed in the 1/23/02 TGB Report, in that none of the supporting data were applicable to such a case.

In order to better quantify a saturation level for the case of a partial liquid heel, API commissioned additional testing in 2004. The purpose of the 2004 study was to obtain additional data points, to be combined with the data collected from similar tanks in 2003, in order to develop a saturation factor for the condition of a partial liquid heel. The results of the 2004 study were presented in the November 15, 2004 report, *Floating Roof Landing Loss: Field Study of A Refill Saturation Factor For An IFRT With A Partial Liquid Heel*,<sup>19</sup> prepared for API by Rob Ferry of TGB.

This report retains the methodology presented in the 1/23/02 TGB Report, and adds the case of a partial liquid heel.

### **1.3 Scope and Limitations of the Model**

The emissions characterized as floating-roof landing losses in this study are those that would be expected to occur if a floating roof is landed in the course of normal operations, and subsequently refilled. This study does not address emissions that may result from additional activities, such as degassing or tank cleaning, that may occur while the tank is empty.

The model is intended for use with any petroleum liquid. The inclusion in the model of the stock liquid's physical properties (i.e., true vapor pressure, vapor molecular weight, and liquid density) appears to effectively differentiate crude oil from gasoline, and therefore no further differentiation was made in the form of product factors or other product-specific adjustments.

The model assumes that the stock liquid used to refill the tank is the same as that stored prior to landing the floating roof. Situations in which there is a change of service (i.e., the tank is to be filled with a different

stock than it had been storing) may warrant differentiating between the stock vapor properties for the arrival and generated components of filling loss.

The model does not address standing idle losses for partial days. It would be conservative (i.e., potentially overestimate emissions) to apply the model to episodes during which the floating roof remains landed for less than a day.

Any emission factor is properly understood as representative of the actual emission rates that are typical for a population of emission points. For a non-uniform population, however, there is an inherent level of uncertainty associated with the application of the general emission factor to any individual emission point. Some of the critical sources of uncertainty in this model of floating-roof landing losses are addressed in the comments on the confidence associated with each step of the model. As noted in these comments, some of the variables have not been well defined, and the values shown are intended to serve only as placeholders – pending further research.

#### **1.4 Proposed Estimating Methods**

Floating-roof tanks were segregated into the following categories for purposes of estimating landing losses:

- a. internal floating-roof tanks (IFRTs) with a full or partial liquid heel,
- b. external floating-roof tanks (EFRTs) with a full or partial liquid heel, and
- c. IFRTs and EFRTs that drain dry.

The two modes of vapor loss (standing idle and filling) are evaluated differently for each of these categories of floating-roof tanks.

##### **1.4.1 Standing Idle Loss.**

The first two categories are described as having a liquid heel, which is a reference to stock liquid remaining in the bottom of the tank as it stands idle after having been emptied (see Figure 4). This heel of stock liquid provides a continuing source of vapors to replace those expelled by breathing (in the case of an internal floating-roof tank) or wind action (in the case of an external floating-roof tank). For each of these cases, then, standing idle loss is a process that is repeated on a daily basis.

The third category is described as drain dry, which refers to a tank that is designed to drain its entire bottom to a sump (see Figure 5). The tank's withdrawal line is located in the sump in a manner that leaves virtually no free-standing liquid in the tank after it has been emptied. The only stock liquid available for evaporation, then, is that which clings to the tank bottom and other wetted surfaces under the floating roof. Once this thin film has evaporated, there is no free stock liquid remaining to replenish vapors under the floating roof. Standing idle loss from a drain dry tank does not continue to occur day after day, but rather is limited to a one-time evaporation of the liquid clinging to the wetted surfaces.

A tank only qualifies as a drain-dry tank if all of the free-standing liquid has been removed. If the tank drains to a sump, but a heel of free-standing liquid is left in the sump, then the tank would be considered to have a partial liquid heel. Flat bottom tanks that have most of the free-standing liquid removed by means of a vacuum truck typically have pools of liquid remaining, and should generally be considered to have a partial heel as well.

##### **1.4.2 Filling Loss.**

Each of these categories experiences filling loss in addition to the standing idle loss. The filling loss is assumed to include vapors from two sources. The first source is those vapors that remain under the floating roof at the end of the standing idle period. These are the vapors residing in the vapor space immediately prior

to the introduction of incoming stock liquid, and are referred to as the arrival component of vapors. Additional vapors are generated by the incoming liquid itself. This source is referred to as the generated component of vapors. Each of these vapor components may be represented by a saturation factor applied to the vapor space volume.

### 1.4.3 Total Landing Loss.

The total loss for a given floating-roof landing episode is the sum of the standing idle loss and the filling loss, as shown in Equation 1.

$$L_T = L_S + L_F \quad (1)$$

where:

$L_T$  is the total landing loss per episode (pounds),

$L_S$  is the standing idle loss per episode (pounds), and

$L_F$  is the filling loss per episode (pounds).

### 1.4.4 Landing Loss Estimation Equations.

Proposed methods for estimating standing idle and filling losses for each of the three categories of tank design are summarized in Table 1. The expressions shown are for estimating the emissions for a single episode of landing the floating roof. An estimate of annual floating-roof landing losses may be obtained by summing the estimated emissions of all the landing episodes that occur during a given year.

Table 1. Summary of Floating-Roof Landing Loss Estimation Methods by Tank Type (per Episode)

|                                              | Internal Floating-Roof<br>Tanks with a Liquid Heel               | External Floating-Roof<br>Tanks with a Liquid Heel                                                    | all<br>Drain-Dry Tanks                                         |
|----------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|
| <u>Standing Idle Loss</u>                    | (daily)                                                          | (daily)                                                                                               | (one-time event)                                               |
| Equation                                     | <u>equations 5 &amp; 10</u>                                      | <u>equations 14 &amp; 10</u>                                                                          | <u>equation 18</u>                                             |
|                                              | $L_S = n_d K_E \left( \frac{P V_V}{R T} \right) M_V K_S$         | $L_S = 0.57 n_d D P^* M_V$                                                                            | $L_S = 0.0063 W_l \left( \pi D^2 / 4 \right)$                  |
|                                              | but $\leq 5.9 D^2 h_{le} W_l$                                    | but $\leq 5.9 D^2 h_{le} W_l$                                                                         | but $\leq (P V_V / R T) M_V S$<br>using the IFRT value for $S$ |
| Standing Idle<br>Saturation Factor,<br>$K_S$ | $K_S$ from <u>equation 8</u> .<br>not to exceed $S$ for filling. | not applicable                                                                                        | not applicable                                                 |
| <u>Filling Loss</u>                          | <u>equation 20</u>                                               | <u>equation 21</u>                                                                                    | <u>equation 20</u>                                             |
| Equation                                     | $L_F = \left( \frac{P V_V}{R T} \right) M_V S$                   | $L_F = \left( \frac{P V_V}{R T} \right) M_V (C_{sf} S)$                                               | $L_F = \left( \frac{P V_V}{R T} \right) M_V S$                 |
| Filling Saturation<br>Factor, $S$            | $S = 0.60$ for a full heel<br>$S = 0.50$ for a partial heel      | but $C_{sf} S \geq 0.15$<br>using the IFRT value for $S$<br>and $C_{sf}$ is from <u>equation 23</u> . | $S = 0.15$                                                     |

Note: Equation 14, for the standing-idle loss of an EFRT, should be regarded as a placeholder. While there are sufficient field and lab data available to demonstrate that wind is a factor in this case, there are not sufficient data to support a particular formulation of the model. In the absence of data, a placeholder was selected that is a relatively simple function of tank diameter, yet yields results that fall within reasonable upper and lower bounds. The other cases lend themselves to derivable theoretical equations, but there are varying degrees of uncertainty in the values assigned to the variables. These uncertainties are discussed in the text of the report.

Where:

$L_S$  is the standing idle loss per episode .....in pounds; ..... as calculated per Table 1.

$n_d$  is the number of days the tank stands  
idle with the floating roof landed .....(dimensionless); ..... as specified by the user.

$$K_E \text{ is the vapor space expansion factor.....(dimensionless); .....} = \frac{\Delta T_V}{T} \left( 1 + \frac{0.50 B P}{T(P_a - P)} \right) \quad (6)$$

$\Delta T_V$  is the daily vapor temperature range .....in degrees Rankine; ..... as calculated from equation 7, or 20°F  
(= 20°R) if unknown.

$T$  is the average temperature of the vapor  
and liquid below the floating roof.....in degrees Rankine; ..... = avg ambient temperature (°F) + 460.

$B$  is a constant from Antoine's equation.....in degrees Rankine; ..... from Table 2.

$P$  is the true vapor pressure of the stock  
liquid .....in psia; ..... as specified by the user, or Table 2.

$P_a$  is the atmospheric pressure at the tank  
location.....in psia; ..... as specified by the user.

$V_V$  is the volume of the vapor space .....in feet<sup>3</sup>; ..... =  $h_v \pi D^2 / 4$

$h_v$  is the height of the vapor space under  
the floating roof.....in feet; ..... as specified by the user. \*

$D$  is the tank diameter .....in feet; ..... as specified by the user.

$R$  is the ideal gas constant.....in psia ft<sup>3</sup> per lb-mole °R; . = 10.731

$M_V$  is the stock vapor molecular weight.....in pounds per pound-mole; as specified by the user, or Table 2.

$$K_S \text{ is the standing idle saturation factor.....(dimensionless); .....} = \frac{1}{1 + 0.053 (P h_v)} \leq S \quad (8)$$

$S$  is the filling saturation factor .....(dimensionless); ..... as stipulated in Table 1.

$$P^* \text{ is a vapor pressure function .....(dimensionless); .....} = \frac{P / P_a}{\left( 1 + [1 - (P / P_a)]^{0.5} \right)^2} \quad (12)$$

$W_l$  is the stock liquid density .....in pounds per gallon; ..... as specified by the user, or Table 2.

$h_{le}$  is the effective height of the stock  
liquid .....in feet; ..... as specified by the user. \*

$L_F$  is the filling loss per episode.....in pounds; ..... as calculated per Table 1.

$$C_{sf} \text{ is the filling saturation correction factor. (dimensionless); .....} = 1 - \frac{(\text{equation 14}) - (\text{equation 5})}{(\text{equation 5}) + (\text{equation 20})} \quad (23)$$

\* See section 4 for adjustment to  $h_v$  and  $h_{le}$  in the case of a cone-bottom tank.