

Atmospheric Hydrocarbon Emissions from Marine Vessel Transfer Operations

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FOREWORD

This publication presents new correlations and emission factors for use in estimating atmospheric emissions and evaporative cargo losses from marine vessel operations. It supersedes the 1976 edition of Bulletin 2514A and the section on marine vessels in the 1959 edition of Bulletin 2514.

The first edition of API Bulletin 2514, *Evaporation Loss from Tank Cars, Tank Trucks, and Marine Vessels*, published in 1959, presented information on evaporative losses from tank cars, tank trucks, and marine vessels. As part of the process of updating that bulletin, the subject matter was separated into two areas of study: marine vessels (Bulletin 2514A) and tank cars and trucks.

In 1976, the first edition of Bulletin 2514A was published as an interim publication and included information that was available at that time on atmospheric emissions resulting from loading gasoline into tankers and barges. Since then, as a result of industry-wide measurement programs, significantly more emission data have become available for other marine operations.

The API Committee on Evaporation Loss Measurement has compiled all available emissions data on marine operations currently practiced in the United States, excluding the operation of crude oil washing. These data have been developed since 1974 and resulted from test programs that used comparable vapor emission measurement procedures. These procedures represent a significant improvement over those used to develop the very limited data upon which the 1959 edition of Bulletin 2514 was based.



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Abstract

This publication presents new correlations and emission factors for estimating total hydrocarbon emissions and evaporative cargo losses for marine vessel loading and ballasting operations. The publication was developed by the American Petroleum Institute's Committee on Evaporation Loss Measurement, a subcommittee of the Committee on Petroleum Measurement. The correlations and factors are based on recent ship and barge emission tests during typical operations.

Correlations are presented for estimating emissions from loading and ballasting of crude oil tankers. To use the crude oil loading correlation, the Reid vapor pressure and temperature of the crude oil must be known. To use the ballasting correlation, the arrival ullage of the cargo must also be known. Use of the correlations are recommended whenever the required input data are available. No statistically significant correlation could be developed for gasoline loading.

The publication presents several emission factors for gasoline loading that differ according to type of vessel, prior cargo, and compartment treatment during the ballast voyage. Similar factors are presented for crude oil loading. Emission factors for ballasting of crude oil tankers are differentiated by the compartment ullage prior to discharging the cargo.

Typical overall emission factors are also provided for use for loading and ballasting operations when the information needed to apply the correlations, or the more detailed factors, is not available.

The correlations and factors for estimating emissions are applicable to product and crude oil tankers currently calling at U.S. ports. These correlations and factors should not be used for estimating emissions from very large crude carriers or for vessels that employ crude oil washing. The publication does not address crude oil loading into barges, gasoline tanker ballasting, or in-transit losses since emission data were not available for these operations.

Evaporative cargo loss estimates were also developed from the emission test data (as presented in Appendix E). Evaporative cargo loss is not necessarily equivalent to an atmospheric emission since a cargo loss occurs whenever cargo evaporates, regardless of whether or not that vapor is displaced from the compartment and emitted into the atmosphere.

Atmospheric Hydrocarbon Emissions from Marine Vessel Transfer Operations

SECTION 1—SUMMARY OF EMISSION CALCULATIONS

1.1 Emission Calculation Procedures

Procedures are outlined in this section to estimate the total hydrocarbon vapor emissions resulting from three different marine transfer operations: (1) the loading of gasoline into tankers and barges, (2) the loading of crude oil into tankers, and (3) the ballasting of crude oil tankers. The emission estimating techniques provide better estimates when applied to a large number of operations or to an entire facility than when applied to a single vessel. The procedures are not applicable for estimating loading or ballasting emissions from very large crude carriers (VLCCs) or from vessels that employ crude oil washing.

Emission factors have been developed at three levels of increasing detail and accuracy for estimating emissions during gasoline and crude oil loading and crude oil tanker ballasting operations. The three classes of factors, all expressed in pounds per thousand gallons of cargo or ballast water loaded, are as follows:

Level 1—Typical Overall Emission Factors

These factors can be used to estimate emissions for a marine terminal when little or no information is available on the prior cargoes or arrival conditions of vessels calling at the terminal and on the frequency that those conditions occur.

Level 2—Category-Specific Emission Factors

These factors differ according to type of vessel, prior cargo, cargo arrival ullage, and compartment treatment during the ballast voyage, as pertinent.

Level 3—Correlations for Estimating Emissions from Loading and Ballasting of Crude Oil Tankers

To use the crude oil loading correlation, the Reid vapor pressure (RVP) and the temperature of the crude oil must be known. To use the ballasting correlation, the arrival ullage of the cargo must also be known. No statistically significant correlation could be developed for gasoline loading.

Use of the Level 3 correlations is recommended whenever the required input data are available. In their absence, use of the emission factors by category (Level 2) is expected to provide the next most accurate emission estimates. The typical overall factors (Level 1) are well-suited for making rough estimates when vessel arrival condition data cannot be developed reliably or are unknown.

1.1.1 GASOLINE LOADING EMISSIONS

If information on the prior cargo and compartment treatment during the ballast voyage is unknown, a typical overall gasoline emission factor of 1.8 pounds per 1000 gallons loaded can be assumed for tanker loading operations, and a value of 3.4 pounds per 1000 gallons can be assumed for barge loading operations. These typical overall emission factors are based on a survey of the distribution of compartment categories at 31 U.S. refinery locations and are shown in Table 1, Level 1.

Emissions from gasoline loading operations can be calculated if the following information is known: (1) type of vessel; (2) prior cargo; (3) compartment treatment during the ballast voyage; and (4) volume of cargo loaded.

The appropriate category and associated average emission factor can then be identified in Table 1, Level 2. By multiplying the selected average emission factor (in pounds per 1000 gallons) by the volume of gasoline loaded (in 1000-gallon units), the total loading emissions (in pounds) can be estimated.

The total gasoline loading emissions can be estimated for a vessel or marine facility by weighting the average emission factors in Table 1 by the percentage of the total cargo loaded into compartments in each category. These compartment categories are defined in 1.2.1.3. The resulting factor is then multiplied by the total volume loaded to obtain the estimated total gasoline loading emissions. This procedure is illustrated by the sample problem in 1.3.1.

1.1.2 CRUDE OIL LOADING EMISSIONS

If the percentages of total cargo volume being loaded into the various compartment categories are unknown, a typical overall crude oil emission factor of 1.0 pound per 1000 gallons loaded can be assumed (Table 2, Level 1).

Emissions from crude oil tanker loading operations can be calculated if the following information is known: (1) prior cargo; (2) compartment treatment during the ballast voyage; and (3) volume of cargo loaded.

From this information and the average crude oil emission factors in Table 2, Level 2, total crude oil loading emissions can be estimated by the same procedure given in 1.1.1 for gasoline loading. This procedure is illustrated by the sample problem in 1.3.2.

Table 1—Total Emission Factors for Gasoline Loading

Category	Vessel	Prior Cargo	Compartment Treatment During Ballast Voyage	Average Emission Factors (lb/1000 gal loaded)	
				By Category (Level 2)	Typical Overall (Level 1)
1	Tanker/ocean barge	Volatile ^a	Uncleaned	2.6	1.8
2	Tanker/ocean barge	Volatile	Ballasted	1.7	
3	Tanker/ocean barge	Volatile	Cleaned	1.5	
4	Tanker/ocean barge	Volatile	Gas-freed	0.7	
		Nonvolatile	Ballasted, cleaned, gas-freed, uncleaned		
5	Barge	Volatile	Uncleaned	3.9	3.4
6	Barge	Volatile	Cleaned, gas-freed	2.0	
		Nonvolatile	Uncleaned, cleaned, gas-freed		

^a Volatile cargoes are those with a true vapor pressure greater than 1.5 pounds per square inch absolute.

If, in addition to the information discussed above for Level 2 (that is, prior cargo, compartment treatment during ballast voyage, and volume of cargo loaded), the crude oil vapor pressure is known, then Equation 1 should be used to account for the effect of crude oil volatility on the average emission factor for any given compartment category.

$$E_T = E_A + E_G \quad (1)$$

Where:

E_T = total crude oil loading emission factor (lb/1000 gal loaded).

E_A = arrival emission factor, associated with the hydrocarbon vapor in the compartment prior to loading (lb/1000 gal loaded).

E_G = generated emission factor, associated with the hydrocarbon vapor generated by evaporation during loading (lb/1000 gal loaded).

Average values of E_A for each compartment category are given in Table 3. E_G can be calculated from the following equation:

$$E_G = 1.84 [0.44 (TVP) - 0.42] \frac{(M) (G)}{T} \quad (2)$$

Where:

TVP = true vapor pressure of loaded crude oil (psia).

M = average vapor molecular weight (lb/lb-mole).

G = vapor growth factor (dimensionless).

T = average vapor temperature ($^{\circ}\text{R} = ^{\circ}\text{F} + 460$).

The true vapor pressure can be determined from Figure 1 if the Reid vapor pressure and the temperature of the crude oil being loaded are known. If specific values of M and T are not known, the average values given in Table 3 can be used in Equation 2. Alternately, E_G can be read directly from Figure 2, which is based on the average values of M , G , and T from Table 3.

Table 2—Total Emission Factors for Crude Oil Loading

Category	Vessel	Prior Cargo	Compartment Treatment During Ballast Voyage	Average Emission Factors (lb/1000 gal loaded)	
				By Category (Level 2)	Typical Overall (Level 1)
1	Tanker/ocean barge	Volatile ^a	Uncleaned	1.1	1.0
2	Tanker/ocean barge	Volatile	Ballasted	0.7	
3	Tanker/ocean barge	Volatile	Cleaned	0.6	
4	Tanker/ocean barge	Volatile	Gas-freed		
		Nonvolatile	Ballasted, cleaned, gas-freed, uncleaned		

^a Volatile cargoes are those with a true vapor pressure greater than 1.5 pounds per square inch absolute.



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Table 3—Average Values of Variables for Crude Oil Loading Emission Equation

Category	Arrival Emission Factors, E_A (lb/1000 gal loaded)	Vapor Molecular Weight, M (lb/lb-mole)	Vapor Growth Factor (dimensionless)	Average Vapor Temperature (°R)
1	0.86	58	1.02	530
2	0.46			
3 and 4	0.33			

The use of the predictive equation (Level 3) discussed above is illustrated by the sample problem in 1.3.2 and provides the most accurate emission estimate.

1.1.3 CRUDE OIL BALLASTING EMISSIONS

If the percentage of ballast water volume loaded into each compartment category is not known, a typical overall emission factor of 1.4 pounds per 1000 gallons can be used for estimating purposes (Table 4, Level 1).

If the volume of ballast water loaded is not known, it can be assumed to be approximately 17 percent of the volume of crude oil unloaded for a typical facility. This value is based on a survey of 31 U.S. refinery locations.

Emissions from crude oil tanker ballasting can be calculated if the following information is known: (1) compartment ullage prior to dockside cargo discharge; and (2) volume of ballast water loaded into compartments that previously contained oil.

Based on this information and the average crude oil ballasting emission factors in Table 4, Level 2, total compartment ballasting emissions can be calculated by multiplying the average emission factor (in pounds per 1000 gallons) by the volume of ballast water loaded (in 1000-gallon units).

The total ballasting emissions can be estimated for a vessel or marine terminal by weighting the average emission factors from Table 4 by the percentage of ballast water loaded into compartments that fall into each category. The categories are defined in 1.2.3.1. This procedure is illustrated by the sample problem in 1.3.3.

If the true vapor pressure of the discharged crude oil and the true ullage prior to discharge of the compartments being ballasted are known, then Equation 3 or Figure 3 should be used to account for the effects of these parameters:

$$E_B = 0.31 + 0.20 (TVP) + 0.01 (TVP) (U_A) \quad (3)$$

Where:

E_B = ballasting emission factor (lb/1000 gal ballast water loaded).

TVP = true vapor pressure of discharged crude oil (psia).

U_A = arrival cargo true ullage, prior to dockside discharge, measured from the deck (ft).

True vapor pressure can be determined from Figure 1 if the Reid vapor pressure and the temperature of the crude oil

being discharged are known. U_A is the true ullage, measured from the deck; it is not the gage ullage, which includes the height of the gage hatch and is typically reported. Figure 3 offers a convenient graphical solution of Equation 3 for discrete values of U_A . The calculation procedure (Level 3) is illustrated by the sample problem in 1.3.3 and provides the most accurate emission estimate.

1.2 Discussion of Variables

Definitions and explanations of the parameters discussed in 1.1 are summarized below.

1.2.1 GASOLINE LOADING VARIABLES

1.2.1.1 Type of Vessel

Shallow draft barges included in the data base had compartment depths of approximately 10 to 12 feet. Ocean barges, with compartment depths of approximately 40 feet, exhibited emission levels similar to tankers.

1.2.1.2 Prior Cargo

Volatile prior cargoes are those with a true vapor pressure greater than 1.5 pounds per square inch absolute, including gasolines and petrochemicals. Examples of nonvolatile prior cargoes are fuel oils and diesel fuels.

1.2.1.3 Compartment Treatment During the Ballast Voyage

An *uncleaned* compartment has had no treatment of any kind except routine heel washing.

A *ballasted* compartment is an uncleaned cargo compartment that has been loaded with ballast water.

A *cleaned* compartment has been water washed.

A *gas-freed* compartment has been cleaned and air-blown, such that the compartment is suitable for entry and hot work (such as welding).

1.2.1.4 Average Emission Factors

The average emission factors are based on a statistical analysis of the available data. (Appendix A describes the measurement procedures and data analysis techniques.) Their development and associated confidence intervals are presented in 2.2 and Appendix B.