AP-42
5th edition
Section 5.2
#3

PETROLEUM TRANSPORTATION AND MKTNG.
AP-42 Section ~~4.4~~ 5.2
Reference Number
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REVISION OF MARINE VESSEL EVAPORATIVE EMISSION FACTORS

Technical Document for Section 4.4, AP-42 Emission Factors

PACIFIC ENVIRONMENTAL SERVICES, INC.
WASHINGTON, D.C. • RESEARCH TRIANGLE PARK, NC • LOS ANGELES, CA

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CHAPTER 1

INTRODUCTION

Many refineries are located on navigable waters and operate marine terminals for transferring gasoline, crude oil, and other petroleum products into marine vessels (tanker ships and barges). Hydrocarbons are emitted from the cargo tanks of marine vessels when liquids are loaded into the tanks, displacing hydrocarbon vapors to the atmosphere. Emissions occur during two distinct types of operations at marine terminals: loading petroleum liquids, and pumping ballast water into the cargo tanks. Hydrocarbon emissions occur principally because volatile petroleum liquids evaporate into the air space above the liquid and are swept out with the air as a new load of fuel enters the tank compartment.

EMISSIONS DURING LOADING OPERATIONS

Loading emissions occur when petroleum products are pumped into the cargo tanks of ships and barges at marine terminals. Emitted vapors result from a combination of the vapors already in the tank compartment at the start of loading (arrival component), and the vapors evaporated from the turbulent liquid being loaded (generated component). The arrival component of loading emissions is dependent upon the nature of the previous cargo and on the compartment treatment prior to the loading (compartment cleaned, ballasted, or left unchanged since the previous offloading). The generated component depends primarily on the properties of the product being loaded that affect its volatility. The loading rate may also affect the amount of emissions generated during loading.

EMISSIONS DURING BALLASTING OPERATIONS

Ballasting is the process of pumping water into empty cargo tanks to maintain a ship's stability and trim on the return voyage after offloading product. In addition to ships, large oceangoing barges often ballast; smaller intercoastal barges do not find it necessary to ballast. Residual hydrocarbon vapors from the previous product load are expelled to the atmosphere as ballast water enters the tank compartments. The amount of ballast emissions depends on the vapor pressure of the product previously discharged and on the true ullage (compartment vapor space, measured in depth below deck) into which vapors were evaporated.

FACTORS AFFECTING HYDROCARBON EMISSIONS

While the source and mechanism of hydrocarbon emissions from marine terminal transfers of gasoline and crude oil are well understood, it is quite another task to quantitatively characterize these emissions as a function of the many variables involved in an individual transfer. Ships and barges may load various products at various rates into tank compartments which have had different histories with regard to previous products, cleaning, etc. All of these variables may affect the quantity of emissions by changing either the arrival or generated component of loading emissions, or the vapor concentration in a tank being ballasted. A more detailed discussion of the factors affecting emissions is contained in Section 4 of the Radian report on marine terminal emissions.[1]

CHAPTER 2

EMISSION FACTOR REVISION EFFORT

In early 1977, EPA requested data from eight major oil companies on hydrocarbon emissions from marine hydrocarbon transfer operations, citing as authority the provisions of Section 114 of the Clean Air Act. The resultant measurement program at the docks of 31 domestic refineries became known as the "8-31 Marine Emissions Study." In addition to measurements of hydrocarbon emissions, several marine practices which may influence emissions were documented during the study. The results of the study, which were unavailable when the previous revision of the emission factors in Section 4.4 of AP-42 was undertaken, served as the primary basis for this revision. The data were released to the American Petroleum Institute's (API's) Committee on Evaporation Loss Measurement, Task Group 2514A, for analysis and incorporation into its Publication 2514A.[2] Many of the assumptions, conclusions, and final emission factors contained in the API publication were utilized in updating Section 4.4.

CURRENT EMISSION FACTORS

The current emission factors for marine vessel operations are contained in Section 4.4 of AP-42, "Transportation and Marketing of Petroleum Liquids." The previous revision to the section was documented in a report by Radian Corporation.[3] Section 2 of that report presents the basis for the changes made to the section that was issued as a part of AP-42 Supplement No. 9, dated July 1979. The principal change involved restructuring several loss correlation equations into a single equation based on the Ideal Gas Law:

$$L_L = \frac{12.46 \ SPM}{T}, \qquad (1)$$

where
- L_L = Loading loss (lb/10^3 gal)
- S = Saturation factor
- P = True vapor pressure of liquid loaded (psia)
- M = Molecular weight of vapors (lb/lb-mole)
- T = Temperature of liquid (°R, where °R = °F + 460°)

Once S values were established (Table 4.4-1 of AP-42 Section 4.4) and properties of the hydrocarbon liquids and vapors were assumed, the emission factors were readily calculated. The emission factors for the loading of petroleum liquids other than gasoline into ships and barges were presented in Table (4.4-3) This table also contains tanker ballasting factors for

4.4-6

gasoline and crude oil, as well as transit loss factors for all products. The emission factors for gasoline loading into ships and barges were presented in a separate Table 4.4-2. These latter factors were based on measurements by oil companies and were to be used instead of the loading loss equation (1). The factors for losses during transit were calculated from the equation:

$$L_T = 0.1 \ PW , \qquad (2)$$

where L_T = Transit loss from tankers and barges ($lb/10^3$ gal transported)
P = True vapor pressure of transported liquid (psia)
W = Density of condensed vapors (lb/gal)

8-31 MARINE EMISSIONS STUDY

Introduction

A testing program was carried out during 1977-78 between EPA and industry for the purpose of supplementing the marine hydrocarbon emissions data that were available at that time. Existing data were available on the loading of gasoline and crude oil into cleaned and uncleaned tankers, and on the loading of gasoline into uncleaned barges. The primary operation for which data were needed was crude oil tanker ballasting. Also, little data were available for gasoline loading into cleaned barges, although this operation occurs relatively infrequently. The major thrust of the program was to build a broad data base for emissions from the ballasting of crude oil tankers. A small amount of data was also gathered for gasoline loading into cleaned barges.

Emission measurements were made at 31 marine terminals owned by 8 oil companies between October 1977 and August 1978. The principal data and calculated emission factors for tests on 63 ballasted tank compartments are summarized in Table 1. Each column in the table contains data for one of the tested compartments as measured on 22 different crude oil ships. The data have been separated into two categories based on true arrival ullage because examination of the frequency distribution of the emission factors reveals a skewness of the data that dictates such a data separation. As a result, it was deemed advisable to calculate different average emission factors for these two categories to reflect both light and "full" cargo loads prior to tank ballasting. Sections 2.2.2 and 2.2.3 discuss the rationale for this treatment of the data.

TABLE 1

CRUDE OIL BALLASTING TEST DATA SUMMARY[a]

	Cargo Compartment ID NO.								
	A-1-2P	A-1-2S	A-1-3C	A-2-1C	A-2-3C	A-2-9C	A-3-7CA	A-3-9CA	A-3-7CB
Test Date	1-27-78	1-27-78	1-27-78	5-23-78	5-23-78	5-23-78	3-2-78	3-2-78	3-21-78
True Arrival Ullage (ft)[b]	2.4	2.4	5.8	1.5	1.5	1.5	1.5	1.4	1.3
Ullage Category[c]	1	1	2	1	1	1	1	1	1
Crude Oil RVP (psia)[d]	3.6	3.6	3.6	4.2	4.2	4.2	4.8	4.8	4.6
Crude Oil Temperature (°F)	60	60	60	82	82	82	62	62	66
Crude Oil TVP (psia)[e]	1.8	1.8	1.8	3.4	3.4	3.4	2.7	2.7	2.8
Ballast Loaded (gal)	1,055,124	1,063,230	1,962,702	772,000	772,000	674,000	651,504	652,974	654,444
Total Hydrocarbons Emitted (lb)	420	580	1,100	406	452	307	840	880	780
Methane, Ethane Content (wt. %)[f]	0.72	0.72	0.91	1.97	1.99	2.28	h	h	h
VOC Emitted (lb)[g]	417.0	575.8	1,090	398	443	300	840	880	780
Total HC Emission Factor ($lb/10^3$ gal)	0.40	0.55	0.56	0.53	0.59	0.46	1.29	1.35	1.19
VOC Emission Factor ($lb/10^3$ gal)	0.40	0.54	0.56	0.52	0.57	0.45	1.29	1.35	1.19

TABLE 1 -- Continued

	Cargo Compartment ID NO.								
	A-3-9CB	A-4-1C	A-4-3C	A-4-4C	A-5-2P	A-5-2S	A-5-4C	A-6-4P	A-6-4S
Test Date	3-21-78	4-26-78	4-26-78	4-26-78	7-1-78	7-1-78	7-1-78	12-3-77	12-3-77
True Arrival Ullage (ft)[b]	1.4	10.4	44.5	1.4	54.5	55.2	45.3	20.3	20.0
Ullage Category[c]	1	2	2	1	2	2	2	2	2
Crude Oil RVP (psia)[d]	4.6	8.5	8.5	8.5	6.9	6.9	6.9	8.6	8.6
Crude Oil Temperature (°F)	66	65	65	65	80	80	80	78	78
Crude Oil TVP (psia)[e]	2.8	6.2	6.2	6.2	5.9	5.9	5.9	7.8	7.8
Ballast Loaded (gal)	652,974	1,557,000	2,080,000	1,805,000	829,500	829,300	634,300	789,363	803,546
Total Hydrocarbons Emitted (lb)	580	1,840	8,010	1,730	1,850	2,480	840	3,055	1,428
Methane, Ethane Content (wt. %)[f]	h	10.2	10.7	10.0	13.3	12.8	9.0	12.6	12.9
VOC Emitted (lb)[g]	580	1,652	7,153	1,557	1,604	2,163	764	2,670	1,244
Total HC Emission Factor (lb/10^3 gal)	0.89	1.18	3.85	0.96	2.2	2.99	1.32	3.87	1.78
VOC Emission Factor (lb/10^3 gal)	0.89	1.06	3.44	0.86	1.93	2.61	1.20	3.38	1.55

TABLE 1 -- Continued

	Cargo Compartment ID NO.								
	A-7-1P	A-7-1S	A-8-8P	A-8-9P	A-8-9C	A-9-1P	A-9-1S	A-9-4P	A-9-4S
Test Date	2-23-78	2-23-78	5-26-78	5-26-78	5-26-78	2-5-78	2-5-78	2-5-78	2-5-78
True Arrival Ullage (ft)[b]	30.3	30.3	1.3	1.2	1.3	2.6	2.6	14.7	15.2
Ullage Category[c]	2	2	1	1	1	1	1	2	2
Crude Oil RVP (psia)[d]	4.1	4.1	7.6	7.6	7.6	4.8	4.8	4.8	4.8
Crude Oil Temperature (°F)	104	104	63	63	63	76	76	76	76
Crude Oil TVP (psia)[e]	4.8	4.8	5.0	5.0	5.0	3.6	3.6	3.6	3.6
Ballast Loaded (gal)	410,004	410,004	451,374	450,198	217,140	878,500	878,500	707,000	707,000
Total Hydrocarbons Emitted (lb)	1,494	1,407	420	392	48	1,439	1,570	1,451	1,719
Methane, Ethane Content (wt. %)[f]	1.39	1.35	3.7	4.2	3.9	34.6	33.0	44.8	44.4
VOC Emitted (lb)[g]	1,473	1,388	404	375	46	941	1,052	801	955
Total HC Emission Factor ($lb/10^3$ gal)	3.64	3.43	0.93	0.87	0.22	1.64	1.79	2.05	2.43
VOC Emission Factor ($lb/10^3$ gal)	3.59	3.39	0.90	0.83	0.21	1.07	1.20	1.13	1.35

TABLE 1 -- Continued

	Cargo Compartment ID NO.								
	A-9-5P	A-9-5S	A-10-1P	A-10-1S	A-10-3P	A-10-3S	A-10-4P	A-10-4S	A-11-2P
Test Date	2-5-78	2-5-78	7-20-78	7-20-78	7-20-78	7-20-78	7-20-78	7-20-78	11-6-77
True Arrival Ullage (ft)[b]	14.2	14.7	5.0	4.6	4.9	4.9	5.0	4.9	5.0
Ullage Category[c]	2	2	1	1	1	1	1	1	2
Crude Oil RVP (psia)[d]	4.8	4.8	4.4	4.4	4.4	4.4	4.4	4.4	7.1
Crude Oil Temperature (°F)	76	76	87	87	87	87	87	87	83
Crude Oil TVP (psia)[e]	3.6	3.6	3.9	3.9	3.9	3.9	3.9	3.9	6.4
Ballast Loaded (gal)	634,900	634,900	634,900	634,900	1,231,650	1,174,530	836,600	841,930	276,318
Total Hydrocarbons Emitted (lb)	1,264	1,588	910	917	1,122	1,266	950	957	382
Methane, Ethane Content (wt. %)[f]	44.4	44.8	41.8	41.8	35.6	35.5	38.2	38.2	6.8
VOC Emitted (lb)[g]	703	876	530	534	723	816	587	591	356
Total HC Emission Factor ($lb/10^3$ gal)	1.99	2.50	1.43	1.44	0.91	1.08	1.14	1.14	1.38
VOC Emission Factor ($lb/10^3$ gal)	1.11	1.38	0.83	0.84	0.59	0.69	0.70	0.70	1.29

TABLE 1 -- Continued

	Cargo Compartment ID NO.								
	A-11-3C	A-11-4P	A-12-1P	A-12-1S	A-12-4F	A-13-2P	A-13-2S	A-13-4P	A-14-1P
Test Date	11-6-77	11-6-77	2-14-78	2-14-78	2-14-78	4-30-78	4-30-78	4-30-78	6-4-78
True Arrival Ullage (ft)[b]	15.0	5.1	2.3	2.4	3.0	4.8	4.8	4.8	2.6
Ullage Category[c]	2	2	1	1	1	1	1	1	1
Crude Oil RVP (psia)[d]	7.1	7.1	7.8	7.8	3.7	5.5	5.5	5.5	0.7
Crude Oil Temperature (°F)	83	83	42	42	45	76	76	76	121
Crude Oil TVP (psia)[e]	6.4	6.4	3.6	3.6	1.3	4.2	4.2	4.2	--
Ballast Loaded (gal)	759,444	533,484	1,030,000	1,032,000	2,927,000	712,152	713,4122	699,216	799,680
Total Hydrocarbons Emitted (lb)	527	939	850	960	1,190	698	684	1,148	600
Methane, Ethane Content (wt. %)[f]	14.6	9.9	11.8	10.4	20.2	6.2	5.1	8.0	11.7
VOC Emitted (lb)[g]	450	846	750	860	950	655	649	1,056	530
Total HC Emission Factor (lb/10^3 gal)	0.69	1.76	0.83	0.93	0.41	0.98	0.96	1.64	0.75
VOC Emission Factor (lb/10^3 gal)	0.59	1.59	0.73	0.83	0.32	0.92	0.91	1.51	0.66

TABLE 1 -- Continued

	Cargo Compartment ID NO.								
	A-14-1S	A-15-1P	A-15-1S	A-15-4C	A-16-2S	A-16-2P	A-17-2C	A-18-6P	A-18-6S
Test Date	6-4-78	10-31-77	10-31-77	10-31-77	1-22-78	1-22-78	4-26-78	5-24-78	5-24-78
True Arrival Ullage (ft)[b]	2.5	6.5	6.5	12.5	1.9	0.9	4.2	5.0	1.5
Ullage Category[c]	1	2	2	2	1	1	1	2	1
Crude Oil RVP (psia)[d]	0.7	4.0	4.0	4.0	3.9	3.9	4.0	4.2	4.2
Crude Oil Temperature (°F)	121	50	50	50	55	55	59	105	105
Crude Oil TVP (psia)[e]	--	1.6	1.6	1.6	1.8	1.8	2.0	5.1	5.1
Ballast Loaded (gal)	803,460	1,008,000	1,008,000	4,009,740	2,041,200	2,041,200	3,844,764	224,400	223,700
Total Hydrocarbons Emitted (lb)	514	495	454	2,526	1,878	1,919	3,023	540	480
Methane, Ethane Content (wt. %)[f]	11.7	2.2	5.5	6.0	6.0	6.6	11.2	7.4	8.3
VOC Emitted (lb)[g]	454	484	429	2,374	1,765	1,792	2,684	500	440
Total HC Emission Factor (lb/10^3 gal)	0.64	0.49	0.45	0.63	0.92	0.94	0.79	2.41	2.15
VOC Emission Factor (lb/10^3 gal)	0.57	0.48	0.43	0.59	0.86	0.88	0.70	2.23	1.97

TABLE 1 -- Concluded

	Cargo Compartment ID NO.								
	A-18-8S	A-19-1C	A-19-3C	A-19-4C	A-20-4P	A-20-4S	A-21-1C	A-21-2	A-21-4
Test Date	5-24-78	7-26-78	8-28-78	8-28-78	10-24-77	10-24-77	3-11-78	3-11-78	3-11-78
True Arrival Ullage[b]	8.4	5.0	27.7	4.7	2.0	2.0	4.0	21.0	5.2
Ullage Category[c]	2	1	2	1	1	1	1	2	2
Crude Oil RVP (psia)[d]	4.2	9.0	11.0	11.0	4.7	4.7	2.9	2.9	2.9
Crude Oil Temperature (°F)	105	120	132	132	74	74	65	65	65
Crude Oil TVP (psia)[e]	5.1	16	24	24	3.4	3.4	1.5	1.5	1.5
Ballast Loaded (gal)	233,900	360,150	1,344,840	2,205,546	1,576,420	1,563,130	321,300	2,856,000	4,157,753
Total Hydrocarbons Emitted (lb)	620	820	3,800	9,400	2,242	2,613	1,216	10,386	12,681
Methane, Ethane Content (wt. %)[f]	9.7	9.8	10.5	6.4	3.2	3.3	0.25	1.5	1.5
VOC Emitted (lb)[g]	560	740	3,400	8,800	2,170	2,526	1,213	10,233	12,492
Total HC Emission Factor ($lb/10^3$ gal)	2.65	2.28	2.83	4.26	1.42	1.67	3.79	3.64	3.05
VOC Emission Factor ($lb/10^3$ gal)	2.39	2.05	2.53	3.99	1.38	1.62	3.78	3.58	3.00

Notes for Table 1

a) Reference 4.

b) Depth of the vapor space above the crude oil prior to dockside discharge, measured from the deck (not the gage ullage, which includes the height of the gage hatch and is the usually reported figure).

c) Category 1: A fully loaded tank compartment with a cargo true ullage of 5 feet or less, prior to dockside cargo discharge.
Category 2: A lightered or previously short-loaded tank compartment with a cargo true ullage greater than 5 feet prior to dockside cargo discharge.

d) Reid vapor pressure of discharged crude oil.

e) True vapor pressure of discharged crude oil at its temperature during discharge.

f) Total percentage by weight of methane plus ethane in the emitted hydrocarbon vapors.

g) Volatile organic compounds (VOC) are assumed for this analysis to consist of total hydrocarbons less methane and ethane content.

h) Test report says "insignificant quantities" of methane and ethane were detected in vapor samples.

Data Base

Table 1 presents the test data corresponding to tests of 63 ballasted tank compartments. An examination of the 21 test reports from the 8-31 Study[4] showed that in four of these tests (designated A-5, A-7, A-20, and A-21), the 10 compartments tested had been lightered (part of the crude oil cargo was discharged) a relatively short time before the cargo was discharged at dockside. This means that the vapor space above the crude oil was increased, and additional hydrocarbons likely evaporated from the liquid surface. Therefore, the emission factor for the subsequent ballasting operation may have been at some intermediate level between that corresponding to low and high ullage tanks. For this reason, it was not possible to assign a single representative arrival ullage figure to these compartments, and the data from these tests were not used in determining average emission factors for the two ullage categories. As a result, 53 of the total 63 tests were used in obtaining averages.

Averages were calculated to compare with those presented by API in Table D-1 of Publication 2514A. Table 2 which follows this page presents these averages for the 53 compartment tests, with API's corresponding figures in parentheses. Values for true vapor pressure (TVP)* and true arrival ullage (U_A) are the measured values from the test reports. The calculated ballasting emission factors were derived from API's empirical equation:

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

where E_B = Total ballasting emission factor (lb/10^3 gal).
TVP = True vapor pressure of discharged crude oil (psia).
U_A = True ullage prior to dockside discharge (ft).

This equation was developed by API from regression and residual analyses, using the test data from the 8-31 study. API then used its empirical equation to calculate estimated emission factors for the two ullage categories. In order to test how well this equation reflects the results of the testing, we have included averages of measured ballasting factors in Table 2 for comparison to the calculated values.

Development of Revised Emission Factors

API's empirical equation 3 was examined on an individual tank basis to determine its accuracy in estimating ballasting emission factors. Table 3 compares individual measured and calculated factors for each of the 53 test compartments comprising the data base. The mean estimated emission factor for the 37 "fully loaded" compartments (Category 1) in the test program is 1.16 lb/10^3 gal, which is exactly the same as the mean value measured in the tests. Therefore, for this group of tests, the equation predicts the overall average emission factor perfectly. For

* The abbreviation "TVP" is used in this document to be consistent with API's usage. However, in Section 4.4 of AP-42, the symbol "P" is used to denote true vapor pressure.

TABLE 2

AVERAGE MEASURED AND CALCULATED EMISSION FACTORS FOR CRUDE OIL BALLASTING[a]

Category[b]	Number of Compartments	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value
Category 1	37 (38)				
TVP (psia)		3.70 (3.76)	1.528 (1.648)	1.3 (1.30)	8.4 (8.40)
U_A (ft)		2.97 (2.71)	1.547 (1.475)	0.9 (0.90)	5.0 (5.00)
E_B (lb/10^3 gal) (calculated)[c]		1.16	0.378	0.61	2.38
E_B (lb/10^3 gal) (measured)[d]		1.16 (1.21)	0.733 (0.740)	0.22 (0.22)	4.26 (4.30)
Category 2	16 (16)				
TVP (psia)		4.71 (4.80)	2.386 (2.327)	1.6 (1.65)	8.4 (8.40)
U_A (ft)		15.09 (19.91)	9.945 (11.862)	5.1 (5.80)	44.5 (44.50)
E_B (lb/10^3 gal) (calculated)[c]		2.08	1.213	0.73	4.32
E_B (lb/10^3 gal) (measured)[d]		1.86 (2.11)	1.133 (1.256)	0.45 (0.51)	3.87 (3.87)

[a] Values in parentheses are those presented in Table D-1 of API Publication 2514A.

[b] Category 1: Compartment ullage of 5 feet or less prior to cargo discharge.
Category 2: Compartment ullage greater than 5 feet prior to cargo discharge.

[c] Average emission factors calculated using API's empirical equation (Equation 3).

[d] Emission factors based on 8-31 Marine Emissions Study test data.

the tests of the 16 compartments in ullage category 2, the equation predicts a mean emission factor of 2.08 lb/10^3 gal, or 11.8 percent higher than the mean measured factor of 1.86 lb/10^3 gal. If the single test showing the greatest discrepancy were discounted as an outlier (Test Compartment A-11-3C), the measured and calculated mean values would become 1.93 and 2.04 lb/10^3 gal, respectively (the equation would overpredict the average emission factor by only 5.7 percent).

Based on the above comparisons for the two ullage categories, the empirical equation developed by API satisfactorily predicts the ballasting emission factor for the complete expected range of arrival ullages and crude oil vapor pressures. The revised AP-42 ballasting emission factors (Table 4.4-4 of Section 4.4 dated 9/85) are calculated using this equation, assuming a true vapor pressure (at 60°F) of 2.8 psia. Since API assumed TVP = 4.0 psia (the average in the tests), the new AP-42 emission factors for ballasting operations are somewhat lower than API's. The ballasting factors in AP-42 should be considered examples which correspond to the particular conditions selected as representative. If the empirical parameters (arrival ullage and crude oil true vapor pressure) are known in a given case, then the equation should be used to calculate more accurate emission factors.

VOC Emission Factors

Since EPA regulations limiting hydrocarbon emissions are expressed in terms of volatile organic compounds (VOC), or the photochemically reactive components of the emissions, the total hydrocarbon ballasting emission factors measured in the tests were converted to VOC emission factors by subracting the methane and ethane content (weight percent) from the total hydrocarbons. Table 1 shows the percentage by weight of methane and ethane measured for each test, as well as the VOC emission factor. The weight percentages range from "insignificant" up to 44.8 percent, with a mean value of 14.3 percent. The VOC emission factor for Category 1 tests ranged from 0.21 to 3.99 lb/10^3 gal, with a mean value of 1.00 lb/10^3 gal. This emission factor is 13.8 percent lower than the corresponding total hydrocarbon factor. The VOC emission factor for Category 2 tests ranged from 0.43 to 3.59 lb/10^3 gal, with a mean of 1.47 lb/10^3 gal. This factor is 21.0 precent lower than the corresponding total hydrocarbon factor.

This analysis for volatile organic compounds indicates that the methane and ethane content of certain crude oils is considerable, having a significant impact on the difference between the VOC and total hydrocarbon emission factors. In cases where an analysis of the crude oil is not available, it appears that an assumption of 15 percent by weight methane and ethane is not unreasonable. An examination of the data in Table 1 indicates no apparent correlation of RVP with methane and ethane content.

LOADING EMISSION FACTORS

The emission factors for gasoline and crude oil loading in API's Publication 2514A represent the results of the latest available test

TABLE 3

COMPARISON OF MEASURED AND CALCULATED BALLASTING EMISSION FACTORS

Ullage Category 1[a]

Test Compartment	Measured Total HC Emission Factor ($lb/10^3$ gal)	Calculated Total HC Emission Factor ($lb/10^3$ gal)[b]	Percent Difference Between Factors[c]
A-1-2P	0.40	0.71	+77.5
A-1-2S	0.55	0.71	+29.1
A-2-1C	0.53	1.04	+96.2
A-2-3C	0.59	1.04	+76.3
A-2-9C	0.46	1.04	+126
A-3-7CA	1.29	0.89	-31.0
A-3-9CA	1.35	0.89	-34.1
A-3-7CB	1.19	0.91	-23.5
A-3-9CB	0.89	0.91	+2.2
A-4-4C	0.96	1.64	+70.8
A-8-8P	0.93	1.37	+47.3
A-8-9P	0.87	1.37	+57.5
A-8-9C	0.22	1.37	+523
A-9-1P	1.64	1.12	-31.7
A-9-1S	1.79	1.12	-37.4
A-10-1P	1.43	1.28	-10.5
A-10-1S	1.44	1.27	-11.8
A-10-3P	0.91	1.28	+40.7
A-10-3S	1.08	1.28	+18.5
A-10-4P	1.14	1.28	+12.3
A-10-4S	1.14	1.28	+12.3
A-11-2P	1.38	1.91	+38.4
A-12-1P	0.83	1.11	+33.7
A-12-1S	0.93	1.12	+20.4
A-12-4F	0.41	0.61	+48.8
A-13-2P	0.98	1.35	+37.8
A-13-2S	0.96	1.35	+40.6
A-13-4P	1.64	1.35	-17.7
A-14-1P	0.75	0.67	-10.7
A-14-1S	0.64	0.67	+4.7
A-16-2S	0.92	0.70	-23.9
A-16-2P	0.94	0.69	-26.6
A-17-2C	0.79	0.79	0.0
A-18-6P	2.41	1.58	-34.4
A-18-6S	2.15	1.41	-34.4
A-19-1C	2.28	1.63	-28.5
A-19-4C	4.26	2.38	-44.1
Mean	1.16	1.16	0.0

TABLE 3 -- Concluded

Ullage Category 2[d]			
Test Compartment	Measured Total HC Emission Factor (lb/10^3 gal)	Calculated Total HC Emission Factor (lb/10^3 gal)[b]	Percent Difference Between Factors[c]
A-1-3C	0.56	0.77	+37.5
A-4-1C	1.18	2.19	+85.6
A-4-3C	3.85	4.31	+11.9
A-6-4P	3.87	3.45	-10.9
A-6-4S	1.78	3.43	+92.7
A-9-4P	2.05	1.56	-23.9
A-9-4S	2.43	1.58	-35.0
A-9-5P	1.99	1.54	-22.6
A-9-5S	2.50	1.56	-37.6
A-11-3C	0.69	2.55	+270
A-11-4P	1.76	1.92	+9.1
A-15-1P	0.49	0.73	+49.0
A-15-1S	0.45	0.73	+62.2
A-15-4C	0.63	0.83	+31.7
A-18-8S	2.65	1.76	-33.6
A-19-3C	2.83	4.32	+52.6
Mean	1.86	2.08	+11.8

a Tests on fully loaded tank compartments with a cargo true ullage of 5 feet or less prior to dockside cargo discharge.

b Calculated emission factor = 0.31 + 0.20 (TVP) + 0.01 (TVP) (U_A) (API empirical equation).

c Percentage difference of emission factors predicted by API empirical equation with respect to those derived from actual test measurements.

d Tests on lightered or previously short-loaded tank compartments with a cargo true ullage greater than 5 feet prior to dockside cargo discharge.

measurements on emissions from loading operations. New Table 4.4-2 in AP-42 essentially reproduces the information presented in Table 1 of Publication 2514A. These emission factors for gasoline loading are averages over a wide range of vapor pressures; no correlation of emission factor with vapor pressure is offered. Therefore, no attempt was made to adjust the figures to a reference RVP, as was done for the ballasting factors (see Section 2.2.3).

API's emission factors for crude oil loading are shown in Tables 2 and 3 of Publication 2514A. The total emission factors in Table 2 are average values composed of contributions from API's Equation (2) for the generated component E_G, and from Table 3 for the arrival component E_A. A single value of E_G was calculated for all of the vessel categories, assuming TVP = 2.8 psia, M = 50 lb/lb-mole, G = 1.02, and T = 520 °R (slightly different from API's assumptions). This produced a generated emission factor contribution of 0.15 lb/10^3 gal. Using API's arrival emission factors of 0.86, 0.46, 0.33, and 0.33 lb/10^3 gal for Categories 1, 2, 3, and 4, respectively (Table 3), we calculated total factors of 1.0, 0.6, 0.5, and 0.5 lb/10^3 gal.

API's four tanker/ocean barge categories for crude oil loading assume a volatile previous cargo and vessel compartments that are, respectively, 1) uncleaned, 2) ballasted, 3) cleaned, and 4) gas-freed. Assuming, as API, that the vessel Category 1 occurs 87 percent of the time; Category 2, 6 percent; and Categories 3 and 4, 7 percent; the overall emission factor for crude oil loading into tankers and ocean barges is 0.94 lb/10^3 gal. This total organic emission factor was inserted into Table 4.4-6 of Section 4.4. The barge loading factors in Table 4.4-6, as well as the loading factors in Table 4.4-5, were calculated from the loading loss equation (Eqn. 1 in this document). Several errors in these calculated emission factors in previous AP-42 Table 4.4-3 were corrected for this revision of Section 4.4.

CHAPTER 3

REFERENCES

1. C.E. Burklin, et al., Background Information on Hydrocarbon Emissions from Marine Terminal Operations, 2 Vols., Radian Corporation for U.S. Environmental Protection Agency, Research Triangle Park, NC, Publication No. EPA-450/3-76-038a and -038b, November 1976.

2. Atmospheric Hydrocarbon Emissions from Marine Vessel Transfer Operations, Publication 2514A, American Petroleum Institute, Washington, DC, 1981.

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4. 8-31 Marine Emissions Study Final Report, 8-31 Technical Advisory Committee, U.S. EPA, Research Triangle Park, NC, December 1978.