# Impact Assessment of New Data On the Validity of American Petroleum Institute Marine Transfer Operation Emission Factors

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Strategies for Today's Environmental Partnership

American Petroleum Institute

STEP

*Strategies for Today's Environmental Partnership*

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# FOREWORD

*Atmospheric Hydrocarbon Emissions from Marine Vessel Transfer Operations* (API Publication 2514A) presents correlations and emission factors for estimating total hydrocarbon emissions and evaporative cargo losses from marine vessel loading and ballasting operations of crude oil tankers.

The test programs from which the marine emissions data base was developed were designed to determine the total hydrocarbon emissions from a vessel's cargo tanks during gasoline and crude oil loading and during cargo tank ballasting after the discharge of crude oil. In general, the measurement procedures and data analysis techniques used in API 2514A follow those developed as part of the Western Oil and Gas Association Marine Measurement Program. The tests were conducted during all seasons of the year and in many regions of the country, usually during routine operations.

The data base for crude oil loading emissions consists of emission measurements from 16 separate vessel operations, each of which represents averages of from 1 to 11 different compartments. The entire data base represents the measured emissions from 67 vessel compartments. These data were separated into three categories, as a function of prior cargo and ballast voyage compartment treatment. The emission data from each separate operation were separately analyzed to determine arrival, generated, and total emission factors.

The data base for crude oil ballasting emissions consists of emission measurements from 54 individual vessel compartments. These data were separated into two categories, as a function of the true cargo ullage in the compartment prior to dockside discharge. The emission data from each compartment were analyzed separately to determine total emission factors.

The correlations and factors for estimating emissions are applicable to product and crude oil tankers currently calling at U.S. ports. However, these correlations and factors should not be used for estimating emissions from very large crude carriers (VLCCs) 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.

API commissioned CH2M Hill to assess the validity and application of the marine vessel loading and ballasting emission factors documented in Publication 2514A. The validity assessment was necessary due to new crude oil loading test data from Valdez, Alaska, which suggests higher crude oil loading emissions for transfer operations than those predicted by API 2514A equations. The Valdez, Alaska testing was conducted by Alyeska Pipeline Service Company and its owner organizations.

CH2M Hill reviewed and critiqued test data bases and emission models obtained through a literature search and performed a direct comparison of emission test data with predictive emission models by API, ARCO and EXXON. The principal focus of the CH2M Hill work was the review of crude oil loading emissions since the new data primarily pertained to this type of operation.

The test data base/emission model critique and emission comparison tasks found that the API crude oil loading emission model appears to adequately predict emissions for tankers ranging in size from 17,000 to 35,000 dead weight tons (dwt) and for tankers being loaded within the lower 48 states (original test data base). Although the model does not appear to apply to crude oil loading of Very Large Crude Carriers (VLCCs – 100,000 to 499,000 dwt) in Valdez, there is no known test data that conflicts with the model's ability to predict crude oil loading emissions from carriers smaller than VLCCs in the lower 48. On average, the API model adequately estimates arrival emissions from crude oil loading operations.

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Suggested revisions are invited and should be submitted to the director of the Industry Services Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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Section 1
# Executive Summary

CH2M HILL was retained by the American Petroleum Institute (API) to assess the validity and application of the marine vessel loading and ballasting emission factors documented in the API publication entitled "Atmospheric Hydrocarbon Emissions from Marine Vessel Transfer Operations," API Publication 2514A, Second Edition, September 1981, reaffirmed August 1987. This validity assessment was considered necessary in light of new crude oil loading test data from Valdez, Alaska, which suggest higher crude oil loading emissions than that predicted by the API 2514A equations. The testing was conducted by the Alyeska Pipeline Service Company and its owner organizations.

The assessment incorporated the following elements, a comprehensive literature search and phone survey of API member organizations for published and unpublished information on hydrocarbon emissions from marine vessel loading and ballasting operations, a review and critique of the test data bases and emission models obtained from the literature search, and a direct comparison of emission test data with predictive emission models by API, Atlantic Richfield (ARCO), and EXXON.

A review of crude oil loading emissions was the principal focus of the study since most of the new data obtained pertained to this marine vessel operation.

The API crude oil loading equations were primarily based on test data from Ventura County, California. The ARCO model was designed to correlate crude oil loading emissions from the Alyeska (Valdez, Alaska) test data. The EXXON model was designed to correlate crude oil and gasoline loading emissions with test data primarily from Baytown, Texas.

## 1.1 Major Study Findings

The major findings of the test data base/emission model critique and emission comparison tasks are as follows:

1. The API crude oil loading emission model appears to adequately predict emissions for tankers ranging in size from 17,000 to 35,000 dead weight tons (dwt) and for tankers being loaded within the lower 48 states (the original test data base). The model does not appear to apply to crude oil loading of Very Large Crude Carriers (VLCCs) in Valdez, Alaska. In addition, there are currently no known test data that conflict with the model's ability to predict crude oil loading emissions from tankers in the lower 48 states that are smaller than VLCCs.

2. The API model on average does an good job estimating arrival emissions from crude oil loading operations.

3. The API model on average underpredicts generated emissions from crude oil loading operations (especially emissions from Valdez, Alaska).

4. The API model does a good job estimating total crude oil loading emissions from the API test data base; however, the model underestimates emissions from the Alyeska test data base.

5. The API and ARCO models do a good job of correlating total crude oil loading emissions to their respective test data bases.

6. The ARCO model overpredicts arrival emissions and underpredicts generated emissions from crude oil loading operations at Valdez, Alaska (Alyeska test data base).

7. The ARCO model does a good job of estimating arrival emissions from the API crude oil loading emission test data base; however, the model overestimates generated emissions from the API test data base.

8. The ARCO model does a good job estimating total crude oil loading emissions from the Alyeska test data base; however, the model overestimates total emissions from the API test data base.

9. Crude oil loading emissions from the Alyeska test data base (on a unit volume loaded basis) were measured on average to be 4 times higher than that measured for the API test data base.

10. The sampling and analytical procedures used in the API and Alyeska crude oil loading emission tests were considered to be of sufficient quality to be used in developing predictive emission models.

11. The API test data base (mainly Ventura County data) contains only a narrow range of tanker sizes (17,000 to 35,000 dead weight tons). In addition, the data base does not include barge loading tests. Barges would be expected to have higher crude oil loading emissions than comparably sized tankers since barges have a larger surface area to compartment volume ratio.

## 1.2 Validity Assessment

As previously indicated, the API crude oil loading emission model underestimates Alyeska's generated emissions. The following are possible reasons why the API model underestimates these generated emissions. Further study would be needed to confirm these possible reasons.

1. A vapor pressure study is currently being conducted by Alyeska. Preliminary results from the study suggest that the API crude oil vapor pressure nomograph may underestimate the true vapor pressure of Alaskan crude oil.

2. Vapor growth factors of 2 percent were observed during the API (Ventura County) testing; while vapor growth factors of 20 percent were typically observed during the Alyeska (Valdez) testing. Although the reason for these higher vapor growth factors are not known, the test data does indicate that in general the Alyeska tests had larger cargo surface areas, crude loading rates, crude loading temperatures, vessel dead weight tonnages, and temperature differences (between the loaded crude and the compartment vapor) than that indicated for the API tests. The API model does not directly account for these parameters. Incorporating these parameters into the API model may improve the overall validity of the model.

## 1.3 Recommendations

### 1.3.1 Crude Oil Loading Emissions

It is recommended that the arrival and generated emission components be recorrelated to include both the original API (WOGA test data from Ventura County, California and the Alyeska test data.) By so doing, the test data base used in the revised API equation would be based on a larger range of tanker sizes (including VLCCs) that are more representative of the fleet population.

It is also recommended that revised parametric equations be developed which predict generated emissions according to two different levels of accuracy. The first equation would be based on TVP (or an equivalent effective volatility measure), vapor growth, and vapor temperature; and essentially follow the form of the existing API equation which is derived from the ideal gas law. The second parametric equation to be developed for the generated emission component would be based on the inclusion of the other parameters listed above that have a significant impact on the generation of emissions.

Lastly, it is recommended that hazardous air pollutants such as benzene be included in the crude oil loading emission estimates. This potentially could entail the inclusion of a table summarizing the percentage of benzene in the hydrocarbon generated as a function of type of crude being loaded.

### 1.3.2 Gasoline Loading Emissions

As additional test data become available, it is recommended that these data be included in a revised emission factor estimate.

### 1.3.3 Crude Oil Ballasting Emissions

As part of future updates, it may be useful to recorrelate crude oil ballasting emissions by including parameters for vapor space volume and exposed surface area along with the volume of ballast water, ullage, and TVP already included in the correlation.

## Section 2
# Introduction

The marine transfer emission factors documented in the American Petroleum Institute (API) publication entitled "Atmospheric Hydrocarbon Emissions from Marine Vessel Transfer Operations, API 2514A" (API, 1987) has been widely accepted by industry and by the Environmental Protection Agency (EPA) as containing accurate equations to calculate emissions from marine transfer operations. However, recent emission testing of crude oil loading operations at Valdez, Alaska, by the Alyeska Pipeline Service Company, together with its owner company organizations, Atlantic Richfield (ARCO), British Petroleum (BP), and EXXON, indicated higher crude oil loading emissions than that predicted by the API equations in API 2514A (Alyeska, 1990).

As a result of this, and a part of the API 2514A reaffirmation process, API retained CH2M HILL to assess the validity of the API 2514A marine vessel loading equations in light of this new Alyeska data and any additional data available in literature and from API members, and to make specific recommendations for improving the validity of API 2514A. Although the evaluation of crude oil loading emissions is the main emphasis of this study, a review and critique of the gasoline loading and crude oil ballasting emission factors and equations in API 2514A was also performed.

This report is divided into five major sections:

1. A summary of the results of a literature search of published information and a telephone survey of unpublished information from API member organizations on marine vessel loading and ballasting emissions (First part of Task 1, Section 3 of the report).

2. A review and critique of the crude oil loading, gasoline loading, and crude oil ballasting emission test data bases and associated emission models (Second part of Task 1, Section 4 of the report).

3. A direct comparison of measured and predicted emissions from marine vessel loading and ballasting operations (Task 2, Section 5 of the report).

4. An assessment of the validity and application of API emission estimates in light of new test data and the reviews summarized in Sections 3 through 5 (Task 3, Section 6 of the report).

5. Specific recommendations on improving the validity and application of API 2514A emission estimates (Task 4, Section 7 of the report).

Section 3

# Literature Search and Survey

CH2M HILL completed a review of the available published literature on marine vessel loading and ballasting emissions, and contacted representatives from EXXON, UNOCAL, Shell, Amoco, Mobil, Chevron, Alyeska, BP, and ARCO to inquire about recent unpublished information on crude oil loading, gasoline ballasting, and gasoline loading emissions and associated predictive emission models that were developed. These representatives were also asked their opinion as to the overall strength and weakness of the API emission equations.

In addition to the API member organizations, source emission testing personnel at local air pollution control districts in Los Angeles, Santa Barbara, and the San Francisco Bay area were contacted in an effort to obtain additional loading and ballasting emission data.

The data and information obtained in the literature search and telephone survey were useful in the qualitative evaluation of marine vessel emissions. The literature search also indicated that the following predictive models would be useful in assessing the validity of the API predictive models:

1. The ARCO PLANO mechanistic model for estimating crude oil loading emissions from Valdez, Alaska (summarized in the Alyeska report)

2. The BP model for estimating crude oil loading emissions from Valdez, Alaska (also summarized in the Alyeska report)

3. A gasoline/crude oil loading emission model developed by EXXON (EXXON, 1976)

With the exception of the Alyeska data and the data used to develop the API 2514A emission factors, there were not other available test data of sufficient content to use in the API emission factor validation process. The test data base used to correlate the EXXON model (mainly EXXON data from Baytown, Texas) were essentially the same as that used to develop the API gasoline loading emission factors.

The literature search reference documents and API member survey comments did, however, provide good information on the mechanisms and parameters involved in generating hydrocarbon emissions during loading and ballasting operations. These references and the results of the phone survey were helpful in reviewing and critiquing the test data bases and associated emission models (Section 4 of this report), and in determining the validity of the API emission models (Section 6 of this report).

Refer to this study's documentation file for the titles of the literature search references that were used in the emission evaluation and for copies of the most substantative phone survey results.

Section 4
# Review of Marine Vessel Emission Data Bases/Models

The following is a review and critique of the test data bases and emission models obtained during the literature search task of the study. The API test data bases and associated emission models, as well as other data bases and models of sufficient content to assist in the API validation process, were evaluated here.

## 4.1 API 2514A, Atmospheric Hydrocarbon Emissions from Marine Vessel Transfer Operations

API 2514A presents correlations and emission factors for use in estimating hydrocarbon emissions from marine vessel transfer operations (API, 1987). The first edition of the publication was published in 1976 and made use of data available at that time for estimating emissions from gasoline loading into tankers and barges. The second edition of the document, published in 1981, and reaffirmed in 1987, used significantly greater quantities of data and added correlations and factors for loading and ballasting of crude oil cargoes. In the document, gasoline loading and crude loading and ballasting operations are separated so the following review will consider each of these activities in turn. All of the data generated for emission estimates for marine vessel loading have been based on measured hydrocarbon concentrations in the vented gases.

### 4.1.1 Review of Sampling/Analytical Procedures Used for the API Test Data Bases

The emission measurements used to develop the API test data base followed procedures outlined in the Western Oil and Gas Association (WOGA) Marine Measurement Program (May 1977). This measurement program is summarized in Appendix C of the WOGA Report entitled "Hydrocarbon Emissions During Marine Loading of Crude Oils, Ventura County, California," August 1977 (WOGA, 1977). In general, emission measurements were made within MSA Model 53 Gascope with the sampling probe inserted into the ullage trunk. Free ullage measurements were made using metering tape or manual gauging.

Periodic grab samples were taken throughout the loading or ballasting cycles. The vapor molecular weight and vapor composition of these samples were determined using gas chromatography or nondispersive infrared techniques. The results of these analyses were used to develop vapor molecular weight and percent hydrocarbon profiles as a function of ullage. These profiles were in turn used to calculate arrival generated and total emission factors.

The data quality assurance/quality control (QA/QC) practices employed during the WOGA emission measurement program appear to be adequate to produce reliable emission results.

### 4.1.2 Gasoline Loading

#### *4.1.2.1 Test Data Base Description and Evaluation*

The data base used to develop gasoline loading factors included tests during the loading of 100 ships and barges. One hundred twenty two individual compartments were loaded. The ships tested ranged in size from approximately 39,000 dwt to 76,000 dwt. The barges were much smaller (less than 10,000 dwt). The vessel fleet at the time of the test program was a mixture of sizes with approximately 36 percent larger than the tested size range. Gasoline loading emission factors were developed by averaging hydrocarbon concentrations measured during the loading operations. The data treatment incorporated six distinctions or categories of factors, accounting for vessel draft (shallow draft vessels such as barges were found to emit different quantities of hydrocarbons than deeper draft vessels such as ocean-going barges and tankers), volatility of prior cargoes (loading vessels that had carried volatile cargoes on the previous voyage resulted in increased emissions), and compartment operations conducted after discharge of the prior cargo (ballasting, gas-freeing, or cleaning). The measurements made included hydrocarbon concentrations in the compartment upon arrival and concentrations at several stages of filling. The total emissions from a loading operation are then calculated as the sum of the arrival and the generated contribution. Loading operations were described as normal during the test program.

#### *4.1.2.2 Variables Identified as Effecting Emissions*

The testing and analysis of data showed that the following parameters have the greatest impact on hydrocarbon emissions from gasoline loading:

- Hydrocarbon content of arriving cargo compartments
  - Prior cargo
  - Compartment treatment during ballast voyage
- Vessel draft
  - Compartment depth

**Arrival Hydrocarbon Content.** The vapors contained in the empty cargo compartment upon arrival for loading will be displaced by the product loaded. The concentrations depend on the volatility of the cargo previously carried in the compartment and on the degree to which the compartment has been cleaned. The concentrations will be reduced if the compartment was used for ballasting because ballasting can clean the compartment and displace residual vapors.

**Vessel Draft.** Vessel draft was noted as strongly affecting emissions with a significant increase for shallow draft barges compared to ocean going barges and tankers. This may be due to increased surface area for evaporation for a similar volume loaded into a shallow draft compartment.

**Other Data Recorded During Testing.** The following data were recorded during each of the testing events:

- Date and vessel name
- Identification number, capacity, and depth of compartments loaded
- Ambient, emitted vapor, and cargo/ballast water temperatures
- Loading rate
- Identification, volume, and Reid Vapor Pressure (RVP) of loaded cargo

These data were not specifically incorporated into the factors presented in API 2514A although an attempt was made to develop a correlation for gasoline loading using some of the parameters.

**Assessment of Gasoline Loading Factors.** The averaging of measured values that was conducted to develop the gasoline loading factors in API 2514A should result in reasonable estimates for average emissions from large numbers of loaded compartments. The 90 percent confidence intervals for each of the factor categories show that as the number of loaded compartments increases, the factors more reliably estimate the total emissions. For single compartment loadings, the 90 percent confidence interval can range by an order of magnitude, suggesting shortcomings in using these factors for limited loading events. Correlations of emissions to compartment specifics (cargo surface area, compartment depth, and type of loading and loading rate), and to the specifics of the cargo (true vapor pressure [TVP], temperature) might improve these emission estimating tools.

### 4.1.3 Crude Oil Loading Emissions

API Publication 2514A presents three different emission estimating techniques for crude oil loading operations. The techniques, varying based on the information known about the crude and loading operation, are increasingly exact with increasing information on the crude and loading operation. If no specific information is available for instance, information in the publication recommends use of an overall factor of 1 pound hydrocarbons emitted per 1,000 gallons crude loaded. This factor is the most general and least reliable of the estimating techniques. If information on the prior cargo and compartment treatment during the ballast voyage are known, a more accurate estimate of emissions is possible. If the crude oil vapor pressure is also known, as well as information on the crude vapor pressure and the ballast voyage compartment treatment, then the most accurate emission estimating techniques is possible. The latter model is considered the most reliable of the techniques and is the focus of the following discussion.

### *4.1.3.1 Test Data Base Description and Evaluation*

The API 2514A data base for crude oil loading consisted of emission measurements from 67 tanker compartments. The data were a collection of emission measurements obtained during 16 tanker operations in which each operation included loading of from 1 to 11 different compartments. The tanker testing was conducted in Ventura County for WOGA (WOGA, 1977). Chevron was the author of the WOGA testing report.

API test data were collected from tankers that ranged in size from 17,000 dwt to 35,000 dwt. During the period of testing, approximately 54 percent of the vessels in the fleet were larger than the tested sizes. In addition, no barges or crude oil washed compartments were included in the model correlations. As indicated, the API crude oil loading test data base includes only a limited tanker size range. This potentially introduces error if the API model is used for tankers outside the size range. The data collected included measured hydrocarbon concentrations upon arrival and periodically throughout the loading event.

**Other Data Collected During Testing.** The following parameters were recorded during a compartment loading event:

- Date and vessel name
- Identification number, capacity, and compartment depth
- Ambient, emitted vapor, and cargo/ballast water temperatures
- Compartment condition upon arrival (ballast voyage treatment and prior cargo)
- Loading rate
- Identification, volume, and RVP of loaded crude
- Specific gravity and viscosity of crude oil

### *4.1.3.2 Description of the API 2514A Predictive Equation*

The API predictive equation was developed from a theoretical analysis of the loading operation. Total emissions were first characterized using the ideal gas law, and then terms were separated to account for an emission because of hydrocarbons in the compartment upon arrival (Ea), and for an emission term for the hydrocarbons generated by evaporation during loading. The separation of terms in the API development is of questionable validity for the following reason:

As per the API analysis:

$$E_{total}\ (E_t) = (C/100)*184*(MV*G/T)$$

where C = the average hydrocarbon concentration for the entire compartment loading event (volume %)

M = the average vapor molecular weight for the entire compartment loading event

G = vapor growth factor

T = vapor temperature (degrees Rankine)

To separate the total loss into a term for the arrival condition and one due to the generated vapor, the portion of the total volume occupied by the generated vapor blanket must be estimated or known. Then, assuming that the compartment is loaded completely and that the vapor space contains a uniform concentration upon arrival, the following equation can be used:

$$E_t = 1.84/T * [(V_a/V_t) * Ca*M_a + (V_g/V_t) * C_g*M_g]$$

where the subscripts t, a, and g refer to total, arrival, and generated respectively, and the other terms are as before.

$V_a/V_t$ will be close to unity because the arrival vapor is assumed uniformly distributed in the compartment that is to be loaded.

$V_g/V_t$ has been determined to be significantly less than unity in other studies, because the generated hydrocarbon blanket occupies a fairly limited volume near the surface of the liquid being loaded.

The separation of terms employed in the API work is as follows:

$$E_t = 1.84 * (C*M) * G/T = 1.84 * (Ca*M_a + Cg*M_g) * G/T$$

In effect, this counts the displaced volume twice, first calculating an emission due to the total volume at the arrival concentration, and then an emission due to the total volume at the generated concentration. The development continues from this separation of terms to a correlation of data for the generated term and producing an emission correlation that fits within the ranges of vessel and crude oil parameters encountered during the measurement program. The following discussion describes the correlation of the emission model with test data. The correlation is based on the theoretical equation with this separation of terms included.

The API equation contains two parts, $E_a$ for emissions due to hydrocarbons in the compartment upon arrival and Eg for emissions associated with hydrocarbon vapor generated by evaporation during loading. The total emissions for a loading event are the sum of the two parts, or:

$$E_t = E_a + E_g$$

(each factor in pounds hydrocarbons emitted per 1,000 gallons crude loaded).

$E_a$, the arrival factor, was not a correlation of data but instead averages of the emissions measured for the types of compartment arrival conditions.

$E_g$, the generated vapor contribution to the total emissions, is defined as follows:

$$E_g = 1.84 \, [\, 0.44\,(TVP) - 0.42 \,]\, [\, (M)(G)/T \,]$$

where:

TVP = true vapor pressure of the crude oil loaded
M = average vapor molecular weight (lb/lbmol)
G = vapor growth factor
T = average vapor temperature (R)

The terms [0.44(TVP) - 0.42] are the concentration in volume percent of the generated vapor. This correlation results from regression and residual analysis of the data with respect to TVP. The equation for $E_g$ was developed using this concentration and the ideal gas law.

The term G, the vapor growth factor, is introduced to account for the increase in vapor volume, beyond the volume of the loaded crude, due to the generation of hydrocarbons by evaporation during loading. It is defined as follows:

$$G = \{\, (Vv - Vl)/\, Vl \} + 1$$

where:

Vv = total vented vapor volume, cubic feet at standard temperature and pressure (STP)

Vl = volume of liquid loaded, cubic feet at STP

The total vented vapor volume was calculated using molar and component material balances on the compartment. These calculations incorporated ullage and cargo surface area as a means to calculate the vapor space volume at the start and end of a loading event. The data base was evaluated to determine an average vapor growth factor. For crude oil loading, this was determined to be 2 percent (G = 1.02), which is recommended for all crude oil loading calculations.

#### *4.1.3.3 Evaluation of API 2514A Predictive Equation for Crude Oil Loading*

The API model was developed to be used for large populations of vessels and numerous loading events. As the numbers of compartments evaluated increases, the model should increase in reliability. The model uses averaged values for the contribution of the compartment's arrival vapor space hydrocarbon concentration to the total emissions. The arrival component then relies heavily on the mixture of prior compartment activities and compartment configurations that API incorporated into the data base. Vessel size and prior cargo compartment treatment, for both of which the API document provides limiting ranges, are critical to the use of such averages. For instance, use of the API correlations for VLCCs or crude-oil washed compartments would rely on an average developed from a data base that did not contain these situations. Beyond the limits of the disclaimer, the API data base was developed in warm-climate regions. The differences between crude temperatures and ambient or compartment wall temperatures may be smaller than cold weather terminals experience. Convective heat transfer in the vapor space would enhance transport of cargo from the liquid surface to the overhead space being displaced during loading. The API equation is based on a dependence of emissions on true vapor pressure. True vapor pressure, as a measure of a crude's tendency to evaporate, is a reasonable variable to base those emissions upon. If the nomograph used to determine TVP from reported Reid vapor pressures underestimates the actual TVP (as is suggested by Alyeska personnel [Alyeska, 1992]), then the API correlation would correspondingly underestimate emissions. The API correlation does not incorporate factors for the surface area of the cargo, nor does it include specific loading rate or time correlation. Turbulence at the liquid surface, and the total surface exposed, as well as the time available for mass transfer, all seem important in this emission scenario.

### 4.1.4 Crude Oil Ballasting Emissions

The API 2514A document contains three estimating techniques for hydrocarbon emissions from crude oil carrier ballasting operations. The techniques increase in accuracy as more information is provided about the operation. The least accurate is the typical overall emission factor of 1.4 pounds emitted per 1,000 gallons ballast water added. If compartment ullage prior to discharge of the cargo is known as well as volume of water added to compartments previously containing oil, the document provides refined emission factors for two categories of these operations. The categories are separated by the extent that the compartment used for ballasting was filled with crude prior to discharge. The most accurate emission estimate can be achieved using the correlation provided for emissions to true vapor pressure and true ullage of the crude oil discharged prior to ballasting. The following discussion focuses on this predictive correlation.

### *4.1.4.1 Crude Oil Ballasting Data Base Description and Evaluation*

The correlation for ballasting operation emissions was developed from hydrocarbon concentration measurements on 54 individual vessel compartments. The vessels tested ranged in size from 42,000 dwt to 121,000 dwt. The fleet was comprised of approximately 79 percent vessels smaller than or equal to 121,000 dwt and 21 percent larger than this size during the period of the testing. The data were separated into two categories based on the true cargo ullage prior to discharge. The hydrocarbon measurements were performed periodically during the ballasting operation.

### *4.1.4.2 Variables Identified as Effecting Emissions*

The measurement and evaluation of concentrations during ballasting operations concluded that the following parameters impact the quantities of hydrocarbons emitted by these operations:

- TVP of the crude oil discharged
- Arrival cargo true ullage
- Volume of ballast water added to the compartment

**True Vapor Pressure of the Crude Oil Discharged.** During the cargo carrying voyage, the vapor space in the compartment will become saturated with vapor in quasi-equilibrium with the cargo. Upon discharge, the compartment walls are covered with a layer of the same crude oil. This layer evaporates into the vapor space emptied during offloading. One measure of the tendency of the crude to evaporate into the empty vapor space is its true vapor pressure.

**Arrival Cargo True Ullage.** The concentration of the vapor vented during a ballasting operation will depend on the volume saturated with vapor during the cargo-carrying voyage, and the surface area of the walls coated with cargo prior to introduction of ballast water. The true ullage of the cargo prior to discharge is a measure of both parameters, assuming a reasonably constant compartment configuration.

**Volume of Ballast Water Added.** The ballast water added displaces the hydrocarbon-rich vapor space. It is reasonable to expect a directly proportional correlation.

**Other data recorded during testing included:**

- Date and vessel name
- Identification number, capacity, and compartment depth
- Ambient, emitted vapor, and cargo/ballast water temperatures
- True ullage before dockside discharge of cargo

- Unloading and ballasting rates; time between unloading and start of ballasting operations
- Identification, RVP, specific gravity, and viscosity of discharged crude oil; volume of ballast water loaded

#### *4.1.4.3 Description and Evaluation of Ballasting Correlation*

Regression and residual analysis of the hydrocarbon concentrations measured during ballasting operations led to the following correlation of emissions to the true vapor pressure of the discharged crude and the true ullage prior to discharge:

$$E_b = 0.31 + 0.20(TVP) + 0.01(U_a)(TVP)$$

where:

$E_b$ = Total ballasting emission factor (lb/1,000 gal water loaded)

TVP = True vapor pressure of discharged crude oil (psia)

$U_a$ = True ullage prior to dockside discharge (ft)

The correlation contains terms that attempt to account for the mass transfer potential and for the space available for the transfer to occur, true vapor pressure, and ullage respectively. To extend this relationship to other vessel size ranges, correlation of the emissions to vapor space volume or exposed surface area might be more universally applicable.

## 4.2 Valdez Tanker Loading—Alyeska Report

The Alyeska Report (1990), is the most recently developed document that quantifies hydrocarbon emissions from crude oil loading of marine vessels. This report documents the approximately 80 tests that were conducted over a 9-month period. The testing was conducted at the Valdez Marine Terminal. The purpose of the testing and evaluation is:

- To quantify the hydrocarbon vapor emissions associated with tanker loading at the Valdez Marine Terminal in Valdez, Alaska.
- To identify the parameters affecting the quantity of hydrocarbon emissions.

The Trans-Alaska Pipeline System accepts crude oil from various sources on the North Slope of Alaska for transport to the Valdez Terminal. The Terminal has facilities for holding and loading the oil into tankers. Oil arriving at the Terminal may be loaded directly from the pipeline into tankers or held temporarily in storage tanks for later loading. The vapors in the tanker's compartments are displaced as crude oil fills the compartments.

ARCO and BP performed separate evaluations of the test data obtained during the study. The objective was to correlate a model that would enable emission losses to be calculated directly from loading data and ship configuration data. The results of this effort were two mechanistic models that predict emissions from crude oil loading operations.

### 4.2.1 Test Data Base Description and Evaluation

The Alyeska emission factor test data used to develop the correlation included data from crude oil tankers only, no gasoline loading data were obtained. Therefore, Alyeska data are not considered applicable for comparison with the API 2514A gasoline loading equation.

The Alyeska testing program commenced in February 1990, and 80 tests were conducted on 20 tankers. All tankers were bottom loaded in basically the same manner. Twenty tankers were outfitted for testing, 11 different groups of tankers were actually tested because 4 of the groups had several tankers identical in construction.

The weight of the tankers ranged from 75 Mdwt to 265 Mdwt, and the volume of cargo ranged from 490 MBbl to 1,800 MBbl. Two different types of cargo vent systems were used; 90 percent of the tankers were equipped with a vent header and mast riser, and 10 percent were equipped with individual compartment vents.

#### 4.2.1.1 *Variables Identified as Effecting Emissions*

The testing and evaluation determined that the following parameters impact the quantities of hydrocarbon emissions from crude oil loading operations:

- Hydrocarbon content of arriving tanker vapor
- Crude oil temperature/tanker temperature
- Volume of crude oil loaded
- Tanker size/configuration
  - Area of the liquid surface in the tank
- Natural Gas Liquid Content of Crude
  - Reid vapor pressure
- Loading Time
- Extent of tanker capacity filled

**Arrival Hydrocarbon Content.** The tanker contains hydrocarbon vapors in the empty compartment when it arrives in port. The quantity of the vapors depend upon the level of cleaning or ballasting, following discharge of the previous cargo. The arrival vapors are a significant factor in loading emissions because these vapors are displaced from the tanker during loading.

**Crude Oil Temperature/Tanker Temperature.** During the crude oil loading (the temperature was recorded periodically) the crude temperature ranged from 61°F to 115°F. The temperature varied as a function of the time spent in tankage. The vapor, ambient air, and seawater temperatures were recorded but apparently used only to establish a range of conditions.

**Crude Volume Loaded.** The volume of crude oil loaded is the fundamental source of vapor emissions. The physical process of crude transfer is the displacement mechanism for causing vapor to be emitted from the tankers. The volume of crude loaded is directly proportional to hydrocarbon emissions.

**Tanker Size and Configurations.** Although not as well understood as other factors, tanker configuration affects hydrocarbon emissions. The surface area available for evaporation is considered to be a factor in hydrocarbon emissions.

**Crude Oil Composition.** The hydrocarbon emissions from tankers are a function of the crude oil volatility, which is a function of composition and temperature. At Alyeska, natural gas liquid (NGL) is added to the crude oil in the production fields. Varying the NGL content of the crude is the only way to adjust the composition. For a 3-week period, the NGL was not added to the crude in the field. This was the field that produced 75 percent of the crude. Test results indicated that varying the NGL content of the crude only had a minor impact on emissions.

**Loading Time.** It was observed during the testing that a longer load time increases emissions, but the effects were small compared to the other factors.

**Extent of Tanker Capacity Filled.** A few of the tankers were filled to 85 percent capacity, but most were filled to greater than 90 percent of capacity. Test results indicated that the effect of incompletely filled tankers was minor.

**Other Data Recorded During Testing.** The following data were recorded during each of the testing events:

- I.G. manifold pressure
- Barometer pressure
- Oil API gravity
- Vapor space temperature profile
- Compartment profile, percent hydrocarbon
- Oil loading rate
- Crude oil sample
- Sample temperature
- Compartment ullage readings
- Seawater temperature
- Ambient temperature
- Tanker history and other relevant data

The data collected were not necessarily incorporated into the equations, but used to establish a range of loading parameters in which the equations are valid.

**Alyeska Vessels Compared to US Fleet Population.** Tank vessels include both tankers that are self-propelled and barges, which are not. The difference between tankers and barges is tank configuration; tankers are deeper and have less surface area, while barges are shallow and have greater surface area. Aside from some oceangoing barges, barges usually travel the inland waterways of the United States. The tankers, other than those used for petroleum importation, are used mainly in coastal traffic, since almost no petroleum is exported.

Tankers in active trade in the United States range in size from less than 1,000 dwt to 406,000 dwt. Data obtained from the U.S. Coast Guard, at the end of 1986, show 152 U.S.-flag tankers of more than 20,000 dwt trading in U.S. water, as well as 990 foreignflag tankers of more than 20,000 dwt. In 1986, there were only 81 U.S.-flag tankers of less than 20,000 dwt.

In 1986, 3,968 barges in the U.S. were certified to carry subchapter D cargoes (flammable liquids, including crude oil and gasoline). Inland barges generally transport between 10,000 barrels and 40,000 barrels of cargo.

The tankers used in the Alyeska emission study ranged in size from 75,000 dwt to 265,000 dwt. Since over 65 percent of the U.S. flag tankers are larger than 20,000 dwt, the tankers used in the Alyeska testing should be considered representative of the overall U.S. fleet tanker population. However, it should be noted that barges were not included in the Alyeska testing program.

#### *4.2.1.1 Review of Sampling/Analytical Procedures Used by Alyeska*

This section summarizes the evaluation of sample collection procedures and analytical methodologies for the purpose of evaluating vapor emissions during tanker loading at the Valdez Terminal. The methods used for the Alyeska study were consistent with those recommended in API publication 2514A and also are currently the best available technologies for the collection and analysis of these types of samples.

**Sample Collection.** The procedures used for vapor sample collection for the Alyeska study are consistent with those recommended by WOGA and documented in API 2514A. The specific procedures used were optimized for the specific sampling conditions of this study. Most notable, precautions were taken to prevent the inclusion of entrained liquids and residual air in the samples, and field measurements of hydrocarbon content in the tanks were made to optimize sample collection.

**Analysis.** The Alyeska document describes the general analytical protocol used for the analysis of samples collected and gives rationale supporting the selection of these methods. In general, the procedures described were used to quantify vapor samples for nonhydrocarbon and hydrocarbon constituents to $C_{10}$. The method used is based on ASTM Procedure D1945 with modifications to enhance the quantification of the $C_{6+}$ constituents. The procedures described are consistent with the guidelines found in API publication 2514A second edition, September 1981, reaffirmed August 1987 (API, 1987).

Publication 2514A describes the methods for determining the hydrocarbon emissions associated with marine vessel transfer operations. Appendixes 3 and 4 to API 2514A provide guidelines for selecting analytical procedures to be used for analyzing vapor samples collected for estimating emissions from the loading and ballasting of marine tankers. The guidelines describe several acceptable approaches and recommend the most preferred. The Valdez study used an analytical protocol that was consistent with the recommended guidelines.

The Alyeska document indicated that aromatic constituents were analyzed by EPA Method 5020, which uses a photo ionization detector with an injection by syringe. It is stated that this method has a relative error of 10 percent because of the injection method. Because of this error, the benzene values were computed from the $C_6$ values, because the error associated with $C_6$ analysis was only 3 percent. It was also assumed that the composition of the crude was stable. This method is acceptable, however, it is desirable to have an independent means to verify a result. The analysis of aromatics by Method 5020 compared to the results obtained by ratio calculations would have been an ideal verification. The error associated with Method 5020 could have been reduced by using an injection loop instead of syringe.

The overall QA/QC practices used by Alyeska to estimate emissions appear to be adequate to produce reliable emission results. The practices also appear to be consistent with API methodologies.

### 4.2.2 Description of ARCO Mechanistic Model

Based on the testing results at the Valdez Terminal, the ARCO Plano Research Center developed a computer simulation program to help understand the factors that influence emissions. The computer simulation provides the most complete understanding of the hydrocarbon vaporization process. However, a simpler mathematical method for correlating tanker emissions was developed so that it can be easily applied to actual loading events. This equation accurately predicts the measured emissions from the Alyeska testing because it is an empirical equation of the test data.

The form of the mathematical equation was developed based on the computer simulations. The actual measured data were used to correlate the exponents of the mathematical equation. The equation giving the best fit is:

$$\text{Ton HC} = X1 * \text{Factor} * T^{X2} (A * \text{Time})^{X3} (\text{Vol oil/Voltanker})^{X4} \text{ppbHC}^{1.25} (1 - \text{yHC/yHCsat})^{0.43} + 448 * \text{Vol oil} * \text{yHC}$$

where:

Ton HC = tons of hydrocarbons emitted

Factor = empirical factor, which depends on tanker class

T = temperature, F

A = area for evaporation, $ft^2$

Time = time to load the tanker, minutes

Vol oil = volume of oil loaded, MMBbls

Vol tanker = volume of inert gas space in oil cargo tanks upon arrival, MMBbls

ppb HC = pounds of HC evaporated per barrel of oil (flash calc)

yHC = mole fraction of hydrocarbon vapors in inert gas upon arrival

yHCsat = equilibrium mole fraction of hydrocarbon in inert gas (flash calc)

The above equation is divided into two terms. The first term or generated emission component accounts for the hydrocarbon emissions generated during oil loading. The second term or arrival component (448*Vol oil*yHC) accounts for the hydrocarbon vapor initially contained in the compartment, which is displaced during loading.

The first term X1 is a conversion factor that accounts for all the necessary conversion units.

The empirically developed tanker "factor" accounts for the differences in sizes of tankers. Each tanker is assigned a "factor" based on its weight in dwt. The factors range from 1.060743 for 265,000 dwt tankers down to 0.804015 for 75,000 dwt tankers.

The crude temperature has been handled by a single temperature term that is raised to an empirically determined exponent X2.

The cross sectional area and loading time are handled by their product raised to an empirically determined exponent X3.

The degree to which the gas space is displaced by oil (volume of oil loaded/volume of tanker) is raised to an empirically determined exponent X4.

The effect of crude oil composition is accounted for by including the volatility of the oil as determined with a flash calculation. The flash calculates the pounds of hydrocarbon evaporated per barrel of oil flashed at 85 F and 15.36 psia, which is the average conditions for the tanker loadings. The 1.25 exponent for this term was determined with hypothetical data.

The term (1-yHC/yHCsat) accounts for the approach to equilibrium between the vapor and liquid phases in the compartment.

The arrival component (448 Vol oil*yHC) is the mass of residual hydrocarbons initially contained in the gas that is displaced by the incoming oil. The coefficient 448 was determined from the ideal gas law.

The ARCO hydrocarbon emissions equation is a correlation from the testing results performed at the Valdez Terminal. The model accurately predicts measured hydrocarbon emissions from the tankers tested. The calculated values compare well to the measured values, with an average error of 1.54 percent and a average absolute error of 11.64 percent.

The ARCO hydrocarbon emissions model assumed that 11 light hydrocarbon components ($C_1$, $C_2$, $C_3$, i-$C_4$, n-$C_4$, i-$C_5$, n-$C_5$, $C_6$, cyclo-$C_6$, benzene, and toluene) were vaporizable. The remainder of the black oil was considered to be nonvaporizable. Based on the hydrocarbon emissions equation, a similar equation was developed for benzene. The format is identical to the hydrocarbon equation; however, the coefficients and exponents were recorrelated for benzene emissions. Benzene emissions are approximately 1 percent of the average total hydrocarbon emissions for the entire Alyeska test data base.

#### *4.2.2.1 Comparison to API 2514A*

A qualitative comparison of the ARCO model to the crude oil loading equation in API 2514A brings to light the following differences between the two equations:

- The ARCO and API equations both identify two types of emissions; arrival and generation emissions. However, the two terms are calculated by different methods. API's arrival term is defined as a single number based upon the tanker's prior cargo and arrival conditions. The ARCO equation arrival term is calculated using the concentration of the arrival vapor and volume of crude loaded.

- The TVP of the crude is directly used to calculate generated emissions using the API model while crude volatility flash calculations are used to calculate generated emissions from the ARCO model.

- The surface area available for evaporation inside the tanker cargo compartment and loading time are used in the ARCO equation to calculate generated emissions. It is known from equations for diffusion that surface area and time are directly proportional to mass transfer. As a result, surface area and loading times would be expected to influence the generation of emissions. In contrast, the API model incorporates a vapor growth factor term (based on test data) to calculate generated emissions.

- The ARCO equation expresses generated emissions as proportional to the square of the crude temperature. The API equation incorporates the crude temperature as a function TVP. The Alyeska report states that the crude oil temperature has a significant impact on the generation of emissions during crude oil loading.

- During the Alyeska testing, crude was bottom loaded into the tankers. Other methods of crude loading cause more turbulence within the cargo hold, which result in higher emissions. Therefore, the data from the

Alyeska study should be used with caution when applied to other loading methods.

- Several other factors considered in the ARCO equation to estimate generated emissions include: the approach to equilibrium between the vapor and liquid phases, percent of capacity the tanker is filled, and the amount of hydrocarbon that is volatilized per barrel of crude.

The ARCO model predicts hydrocarbon emissions from crude oil loading only. The API 2514A document also contains equations for gasoline loading and crude oil ballasting emissions.

The ARCO equation appears to be more detailed than the API crude oil loading equation. However, the ARCO equation is based only on testing performed at the Valdez Terminal. Developers of the ARCO equation indicated that the ARCO model should not be used to calculate emissions loading operations in any locations other than the Valdez Terminal.

It should also be noted that the API crude oil loading emission model was intentionally designed to be less detailed than that developed by ARCO since the API model is intended to have a much wider application and be most applicable to large emission inventories.

### 4.2.3 Description of BP Mechanistic Model

Unlike the ARCO equation, the BP mechanistic model is not a simplified mathematical method, but rather a computer simulation program. The computer model was developed from the testing data at the Valdez Terminal. The model was tuned to tanker emission data for the major tanker classes, and used to predict hydrocarbon emissions as a function of the following parameters:

- Area—cargo surface area available for evaporation
- Boundary layer thickness—the distance from the gas/oil interface to where the vapor space is well mixed with hydrocarbon
- Change in vapor space temperature—between initial and final temperatures recorded during the loading
- Crude loading rate
- Molecular weight of vaporizing hydrocarbon—determined in advance from flash calculation

- Maximum hydrocarbon mole fraction and gas/oil interface—determined from flash calculation
- Average vapor space pressure during loading
- Average crude temperature during loading
- Volume of crude loaded
- Tanker compartment arrival conditions (i.e., vapor volume, vapor temperature, mole fraction hydrocarbon)

The BP model was correlated for the data obtained during the testing at the Valdez Terminal in Alaska. The model predicts hydrocarbon emissions to within +/- 10 percent.

The model was developed by the BP Research Center in Warrensville, Ohio. The model is a computer simulation program and not readily available for commercial use.

**Model Limitations.** The following is a discussion of the use and applicability of the BP model for estimating crude oil loading emissions, as well as the strengths and weaknesses of the model relative to the API equations. This information is based on discussions with BP personnel (BP, 1992).

The BP model indicates that the following parameters have the greatest impact of total emissions:

- Boundary layer thickness
- Difference in hydrocarbon content between the gas/oil interface and the bulk gas—this addresses the effective volatility of the crude, not only the vapor pressure but the vapor composition
- Arrival hydrocarbon content
- Vapor growth factor

The small boundary layer thicknesses calculated from the BP model could be due in part to convection currents generated from the temperature gradient between the compartment wall temperature and the crude oil loading temperatures encountered in the Valdez, Alaska, tests. These convection currents could result in higher emissions in colder climates such as Alaska.

The difference in hydrocarbon content between the gas/oil interface and the bulk gas is principally driven by the effective volatility of the crude. The TVP function does not really indicate the effective volatility of the crude since the heavier hydrocarbon components, such as butane and pentane (which have lower TVPs than the average crude TVP) contribute the most on a weight basis to the overall emission rate.

Vapor growth factors as high as 20 percent were commonly observed during the Alyeska testing. There was great variation in the vapor growth factors, but were always noticeably higher than the 2 percent used in the API 2514A equation.

## 4.3 EXXON Marine Vessel Loading Emission Model

In 1976, EXXON researchers published a correlation of hydrocarbon emissions from gasoline and crude oil loading to the various physical parameters involved (EXXON, 1976). The EXXON model was developed in response to a need to better characterize emissions from marine vessel loading.

### 4.3.1 Test Data Base and Evaluation

The data base used to develop the EXXON correlation consisted of data obtained during the loading of approximately 70 ship and 20 barge tanks. The vessels were loaded primarily with motor gasoline at Baytown, Texas, although there were a limited number of data points generated during crude oil loading at Kharg Island, Iran. The data consisted of measured hydrocarbon concentrations before loading began, during initial loading, and periodically during the remainder of the loading event. The test data base for motor gasoline loading was essentially identical to that used to correlate the API gasoline loading emission factors.

#### *4.3.1.1 Variables Identified as Effecting Emissions*

The testing and evaluation performed during the development of the EXXON correlation concluded that the following parameters can be used to describe hydrocarbon emissions from marine vessel loading:

- Hydrocarbon content of cargo compartments upon arrival
- Volume of cargo loaded
- Cargo TVP
- Cargo surface area
- Final ullage of the loaded cargo

**Arrival Hydrocarbon Content.** The hydrocarbon concentrations in a compartment prior to loading are a function of the previous cargo and the tank cleaning operations conducted after discharge of the previous cargo. The hydrocarbons in the compartment upon arrival may constitute a significant portion of the total emissions because of a loading event.

**Volume of Cargo Loaded.** The volume of cargo loaded is directly proportional to the volume of vapors displaced from a cargo compartment.

**Cargo TVP.** The TVP of a cargo is a measure of its tendency to evaporate. It is expected that hydrocarbon vapors generated during loading activities would be a strong function of vapor pressure of the cargo.

**Cargo Surface Area.** The cargo surface is the source of hydrocarbons that evaporate into the vapor space during loading. The hydrocarbon content of the vapor space close to the surface is higher than that at a greater distance. A greater surface area then will provide a larger hydrocarbon-rich blanket to be emitted at loading completion.

**Final Ullage of the Cargo Compartment.** EXXON researchers determined that, early in the loading process, a blanket richer in hydrocarbons than the remainder of the vapor space develops just above the surface of the cargo being loaded. The blanket, once formed, remains fairly static until it is displaced to the atmosphere upon completion of loading. A compartment that was not completely filled would be expected to emit less of the blanket than one that was completely filled. EXXON's final ullage correction factor attempts to correct for this behavior.

### *4.3.1.2 The EXXON Model*

The EXXON researchers developed the following correlation of data to predict hydrocarbon emissions from vessel loading. The equation was developed to apply to both gasoline and crude oil loading operations.

$$E = [\ (C)(V)/100] + [\ (P)(A)(G-U)\ ]$$

where:

E = the total volume of pure hydrocarbon emitted in cubic feet at the loading conditions

C = the arrival hydrocarbon concentration (% v/v)

V = the volume loaded in cubic feet

P = the cargo TVP in psia

A = the cargo surface area in square feet

G = the correlated generation coefficient of 0.36 $ft^3/(ft^2*psia)$

U = a final ullage correction for G in $ft^3/(ft^2*psia)$

**Comparison to API 2514A.** The API and EXXON correlations both identify two separate reasons for hydrocarbon emissions during the loading of marine vessels: the vapors in the tank upon arrival for loading and the vapors generated during loading. The API values for the arrival concentrations are based on averages for the arrival conditions while the EXXON model allows them to be calculated from the volume loaded and the arrival concentration.

The volume of cargo loaded is directly proportional to the total emission in the API model and directly proportional to the arrival portion of the emissions in the EXXON model.

Both models incorporate the TVP of the crude loaded in the calculation of the generated portion of the emissions.

The EXXON model incorporates the surface area of the cargo and a term to correct compartments not completely filled into the generated portion of the emissions. In contrast, the API model incorporates a vapor growth factor (from test data) into the calculation of generated emissions.

As indicated, the EXXON model appears to include more of the mechanisms that affect the nature of the hydrocarbon emissions from vessel loading operations. The surface area of the cargo is important in that it is the source of the hydrocarbons generated during loading. Considering that there is a zone of limited extent above the cargo surface that is richer in hydrocarbons than the rest of the vapor space, if a tank is not completely filled, less rich vapor space would be displaced. Final ullage would appear to be a necessary parameter to describe this.

## Section 5
# Comparison of Vessel Loading/Ballasting Emission Estimates

The crude oil loading comparison test data base, shown in Table 5-1, consists of 25 emission tests from Alyeska (a representative sample of the 80 Alyeska tests) and 18 tests from the lower 48 states (principally from Ventura County, California). The Alyeska data consists of tankers ranging from 75 to 265 Mdwt and the lower 48 data consists of tankers ranging from 17 to 35 Mdwt.

Table 5-2 is a breakdown of measured, arrival, generated, and total emissions for crude oil loading. The API and Alyeska arrival emission differ by about 20 percent. However, generated emissions for Alyeska were eight times higher than the API measured emissions. The Alyeska total measured emissions were over three times higher than the API data set.

## 5.1 Crude Oil Loading Emissions Predictions

The crude oil loading emission comparison tables, Tables 5-3 through 5-5, summarize the parameters used to estimate emissions for the API, ARCO, and EXXON crude oil loading models, respectively. These tables provide the percent error (or difference) between the predicted and measured emissions for each entry in the crude oil loading comparison data base, as well as provide calculations for the average and absolute average percent error (or difference) for the entire comparison data base. The tables also summarize the average predicted and measured emissions for the data base.

The following three sections (Sections 5.1.1 to 5.1.3) are a summary of the findings from the these three tables.

### 5.1.1 API Model Crude Oil Loading Emissions Predictions

Table 5-3 shows the crude oil loading data base emissions as calculated with the API model. The API 2514A model predicted emissions for the Alyeska data base (tests 1-25) are 18 to 76 percent lower than the measured emissions. This range was 37 percent to 71 percent lower for Alyeska tankers less than 100 Mdwt and 58 percent to 72 percent lower for Alyeska tankers greater than 150 Mdwt. Emissions from the two very large crude carriers (VLCCs) (tankers greater than 180 Mdwt) from the Alyeska comparison data base were predicted to be approximately 60 percent lower than the measured emissions.

The API 2514A predicted emissions for the lower 48 state data base (tests 26-43) ranged from 75 percent higher to 65 percent lower than the measured emissions. The majority (16 out of 18 tests) predicted emissions 6 to 65 percent lower than the measured emissions. Only two tests predicted higher than measured emissions.

The majority of the API predicted arrival emissions were higher than the predicted generated emissions. This occurred most of the time for Alyeska data base in part since all but one of the tankers had a Category 1 arrival condition (i.e., uncleaned compartments, volatile prior cargo).

### 5.1.2 ARCO Plano Model Crude Oil Loading Emission Predictions

Table 5-4 shows the crude oil loading data base emissions as calculated using the ARCO model. The ARCO Plano model predicted emissions for the Alyeska data base range (tests 1-25) from 24 percent higher to 27 percent lower than the measured emissions. This range was from 2.4 percent higher to 24 percent lower for Alyeska tankers less than 100 Mdwt and between 3.3 and 27 percent lower for Alyeska tankers greater than 150 Mdwt. Emissions from the two VLCCs from the Alyeska comparison data base were predicted to be 3.3 percent and 19 percent lower than the measured emissions.

The ARCO Plano predicted emissions for the lower 48 state data base (test 26-40) are 90 percent to 1409 percent (2 to 15 times) higher than the measured emissions.

The majority of the ARCO predicted arrival emissions for the Alyeska test data were higher than the predicted generated emissions. In contrast, all of the ARCO predicted arrival emissions for the lower 48 state test data were **lower** than the predicted generated emissions.

### 5.1.3 EXXON Model Crude Oil Loading Emission Predictions

Table 5-5 shows the crude oil loading data base emissions as calculated using the EXXON model. The EXXON model predicted emissions for the Alyeska data base range (tests 1-25) from 26 percent higher to 64 percent lower than the measured emissions. This range was from 40 to 52 percent lower for Alyeska tankers less than 100 Mdwt (except for one test point 9 percent higher than measured) and between 38 to 65 percent lower for Alyeska tankers greater than 150 Mdwt. Only 3 out of the 25 Alyeska comparison data base entries used in this comparison predicted higher emissions than that measured. Emissions from the two VLCCs from the Alyeska comparison data base were predicted to be 49 and 24 percent lower than the measured emissions.

The EXXON predicted emissions for the lower 48 state data base (tests 26-40) are 25 percent to 701 percent (1.25 to 8 times) higher than the measured emissions.

## 5.2 Comparison of ARCO, EXXON, and API 2514A Crude Oil Loading Emission Estimates

A series of tables (Table 5-6 through 5-8) were prepared in order to compare total, arrival, and generated crude oil loading emissions between the ARCO, EXXON, and API models. Table 5-9 provides a comparison of API model emissions using the API nomograph—determined TVP value and an "adjusted" (2.5 pounds higher) TVP, which may be more indicative of the "actual" TVP.

The following paragraphs summarize the results of this series of tables.

Table 5-6 compares the total emission results of ARCO, EXXON, and API crude oil loading equations. Overall, the ARCO model predicted the highest crude oil loading emissions followed by the EXXON model. The API model predicted the lowest emissions values of the three equations.

The API model calculated values lower than the EXXON model by 16 to 86 percent. The average difference between API and EXXON was 45 percent.

The API model calculated emission values lower than the ARCO model by 21 to 87 percent. The average difference between API and ARCO was 61 percent.

The EXXON model compared to the ARCO model fairly well; the values calculated by EXXON were 59 percent lower to 26 percent higher than the ARCO equation. The average difference between EXXON and ARCO was 29 percent.

Crude oil loading emissions can be broken down into two categories: arrival emissions and generated emissions. The API, ARCO, and EXXON equations each have an arrival term and a generated term. Tables 5-7 and 5-8 compare the arrival and generated emissions to total emissions for each of the three equations. The ARCO equation predicts the lowest average arrival emissions of the three equations, 55 percent of the total emissions. The predicted arrival emissions vary between 1 and 98 percent of the total emissions. The average generated emission values were calculated to be 45 percent of the total emissions.

The API equation predicts that the average arrival emissions are about 65 percent of the total emissions. The arrival emissions vary between 39 and 98 percent of the total emissions. The average generated emission values were 35 percent of the total emissions.

The EXXON equation predicts the highest average arrival emissions of the three equations, 80 percent of the total emissions, with a range of 35 to 95 percent. The average generated emission values were calculated to be 20 percent of the total emissions.

According to Alyeska, a study to be released indicates that TVP, as determined from the API 2514A nomograph, may be 2 to 2.5 pounds lower than the "actual" TVP of the crude (Alyeska, 1992). Table 5-9 shows the difference in predicted crude oil emissions using the API model values adjusted up by 2.5 psia. The adjustment increases predicted emissions by an average of 20 percent. Still, the difference between the adjusted predictions and the measured values is over 40 percent.

## 5.3 Comparison of EXXON and API 2514A Gasoline Loading Emission Estimates

The gasoline loading comparison test data base, shown in Table 5-10, consists of over 120 emissions tests conducted at EXXON's Baytown, Texas, loading facility. Of the vessel sizes that are known, the tankers and barges range in size from less than 10,000 dwt to 75,000 dwt.

Table 5-11 compares gasoline loading emissions using the API 2514A equation with measured emission values. The average difference between calculated and measured is 63 percent. The calculated values range between 790 percent higher to 600 percent lower than the measured values. The API emission values are calculated by multiplying the volume of gasoline loaded by a scaling factor that is based on the tanker's prior cargo and compartment treatment prior to loading.

Table 5-12 compares gasoline loading emissions using the EXXON equation with measured emission values. There were only six gasoline loading tests that have sufficient data to use the EXXON equation to calculate emissions. The average difference between the calculated and measured values is 58 percent.

Table 5-13 compares the API and EXXON equation calculated emissions. The EXXON equation calculates the higher emission values. The average difference between the two equations is 50 percent.

## 5.4 Comparison of API 2514A Crude Oil Ballasting Emission Estimates With Actual Test Data

The crude oil ballasting comparison test database, shown in Table 5-14, consists of over 60 tests conducted at various locations in the lower 48 states. Of the vessel sizes that are known, the tankers and barges range in size from 49,000 dwt to 120,000 dwt.

Table 5-15 compares crude oil ballasting emissions using the API 2514A equation with measured emission values. The average difference between calculated and measured values is 50 percent. The calculated values range between 537 percent higher to 82 percent lower than the measured values.

## 5.5 Summary of Direct Crude Oil Loading Emission Comparisons

A series of bar charts (Figures 5-1 through 5-3 and Figures A-1 through A-6 in Appendix A) were developed which graphically present the measured and predicted arrival, generated, and total crude oil loading emissions from the Alyeska (Valdez, Alaska) and API (Ventura County, California) test data bases. The predicted emissions were based on the API, ARCO, and EXXON models. Figures 5-1 through 5-3 present the average arrival, generated, and total crude oil loading emissions, while Figures A-1 through A-7 present the emission results from each of the individual tests used in the comparison data base. A representative sample of the Alyeska test data and most of the API test data were used to develop these bar charts.

Figures 5-2 and 5-3 also present the average generated and total emissions for the Alyeska data base using an adjusted TVP (API nomograph TVP plus 2.5 pounds). These graphs were added to demonstrate how the API-predicted emissions would change if the "actual" TVP of Alaskan crude is in fact higher than that indicated through the use of the API 2514A nomograph (as is suggested by Alyeska personnel [Alyeska, 1992]).

Figure 5-1 compares the average measured arrival emission with the predicted arrival emissions for each of the three equations. The following observations can be made from this figure.

- The API equation on the average does a good job estimating arrival emissions for the API and Alyeska data sets.
- The ARCO equations does an excellent job of estimating arrival emissions for the API data set; however, it overestimates by more than two times the arrival emissions for the Alyeska data set.
- The EXXON equation overestimates the arrival emissions for both API and Alyeska data by a factor of 3 and 2, respectively.

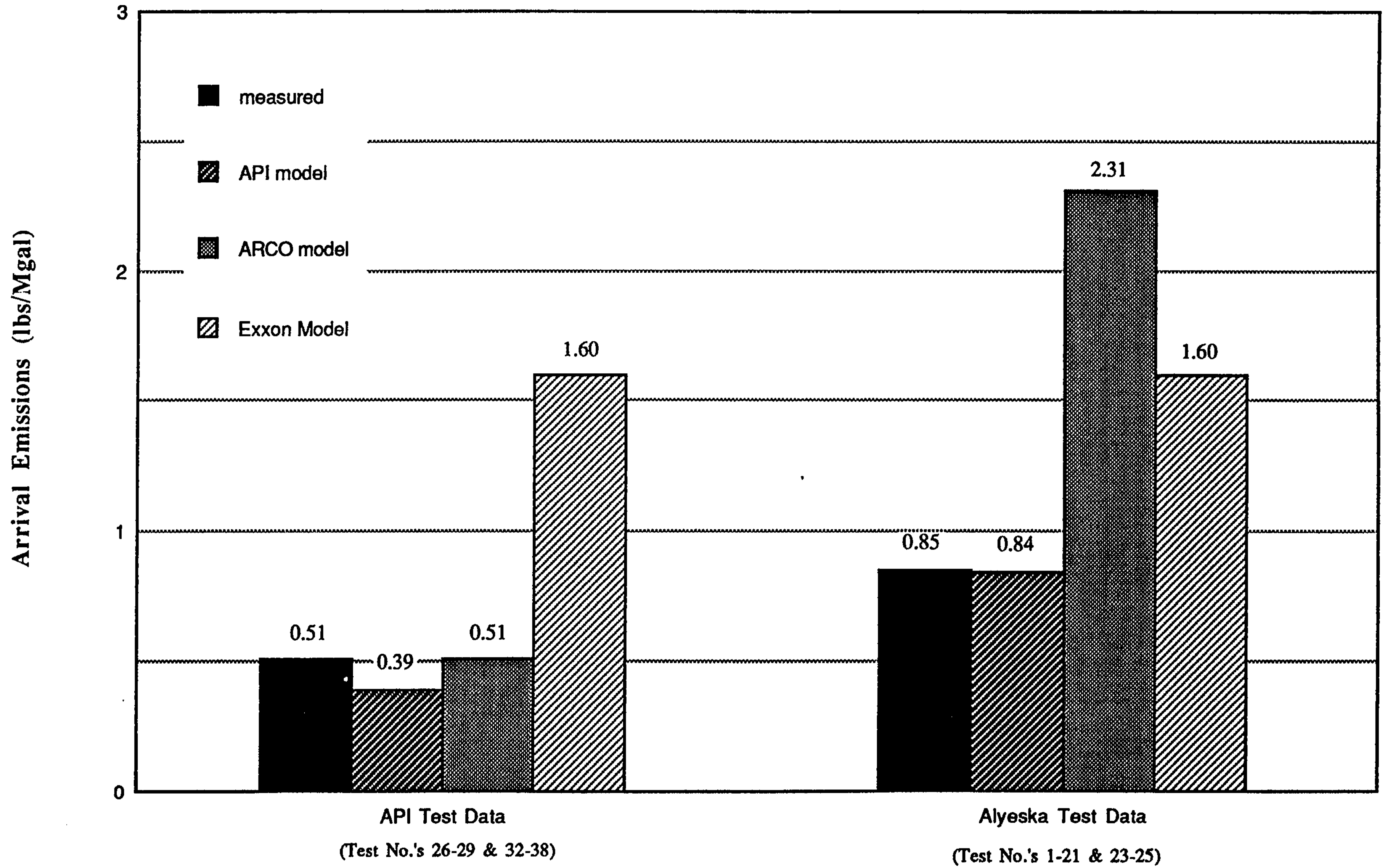
Figure 5-2 compares the average measured generated emissions with the predicted generated emissions for the three equations and the API equation with adjusted TVP. The following conclusions can be drawn from this figure:

- The measured generated emissions were all less than 1 lb/Mgal loaded for the API data set, but were consistently higher, greater than 2 lb/Mgal loaded on average, for the Alyeska data.
- The API equation underestimates emissions for the API data set. The API equation with and without adjusted TVP underestimates (by a factor of four) the measured values for the Alyeska data.

# Figure 5-1

## Crude Oil Loading

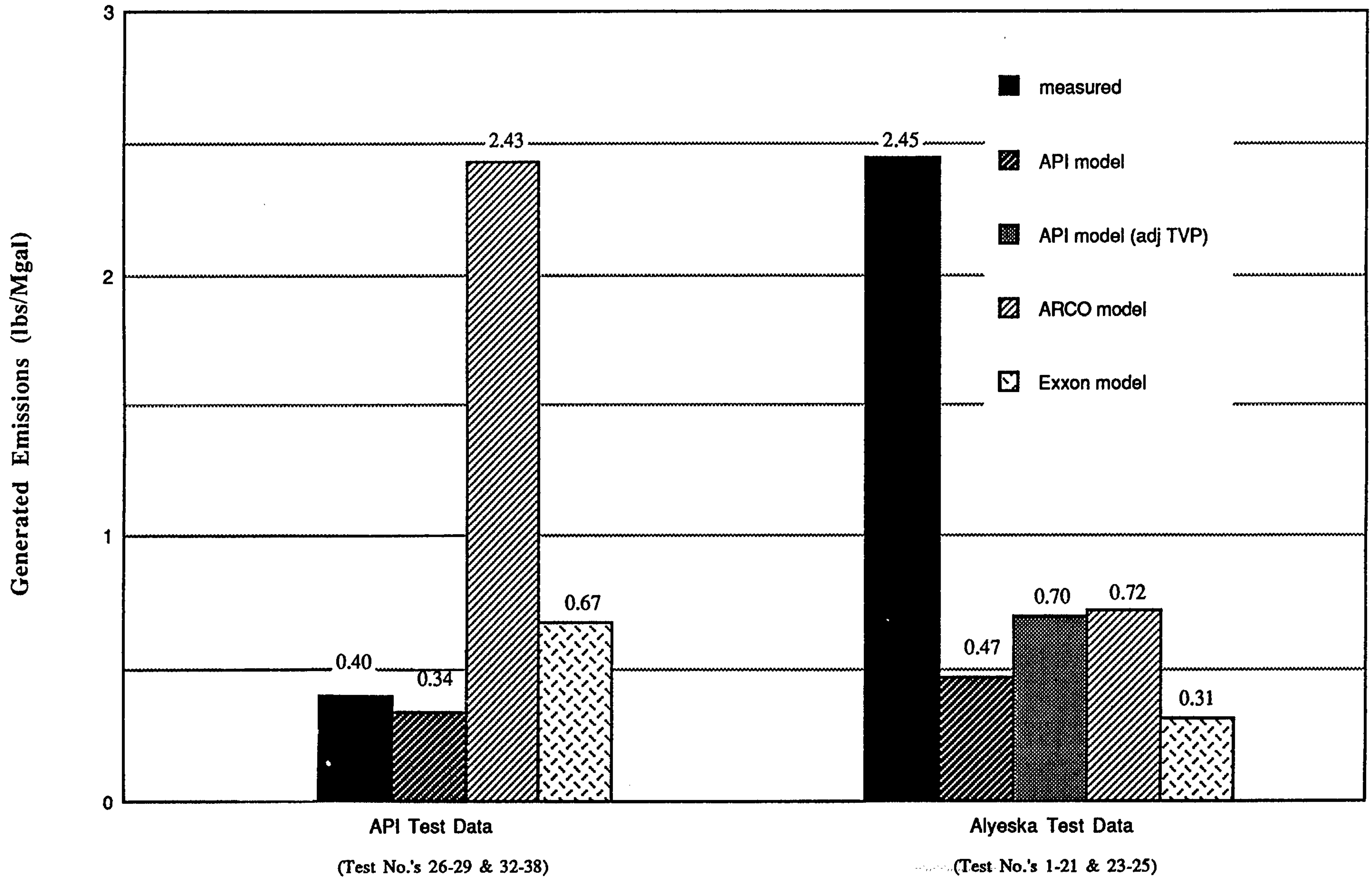
## Average Arrival Emissions



# Figure 5-2

## Crude Oil Loading

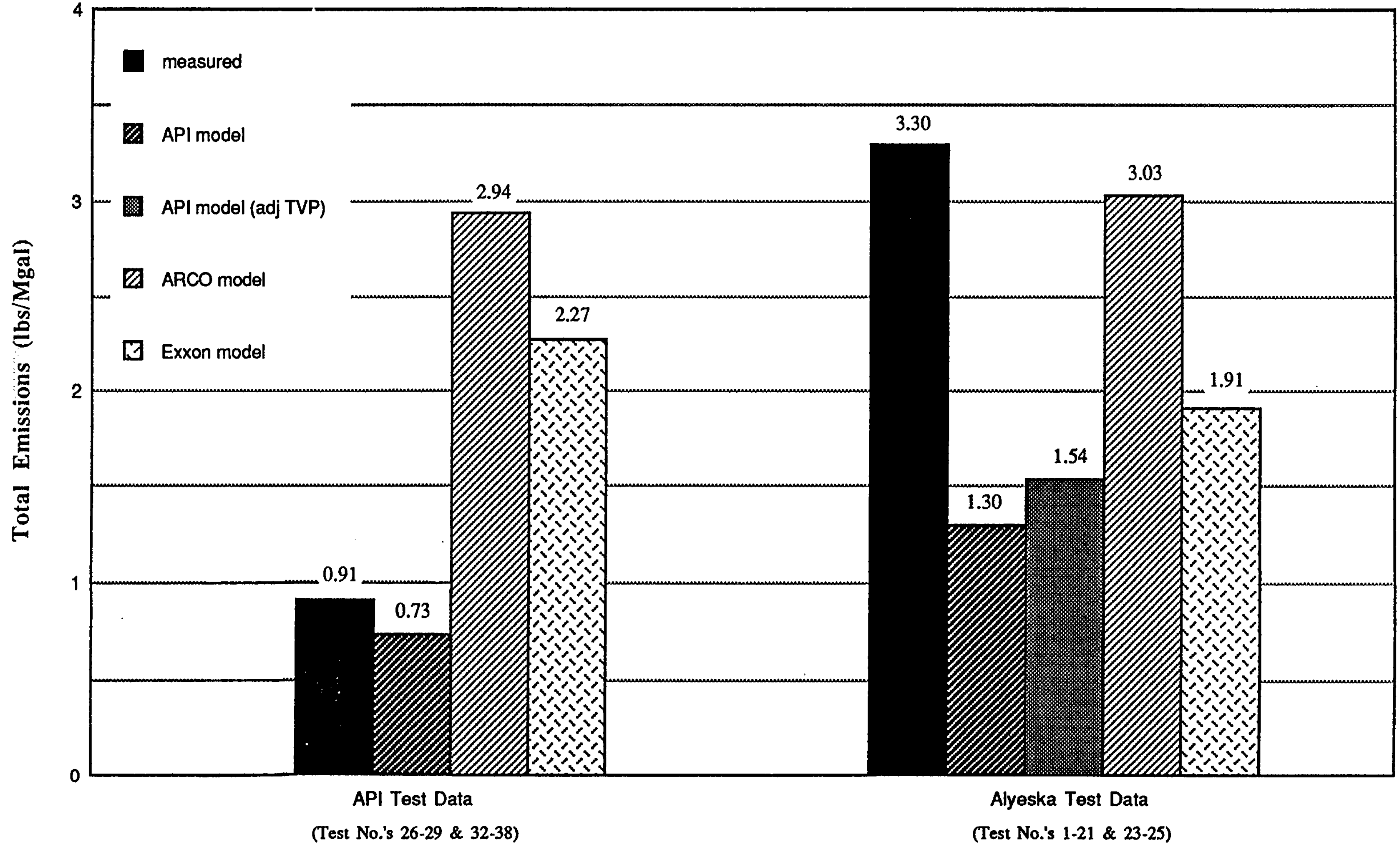
## Average Generated Emissions



# Figure 5-3

## Crude Oil Loading

## Average Total Emissions



- The ARCO equation overestimates the generated emissions for the API test data by a factor of 15; however, it underestimates generated emissions by a factor of 3 for the Alyeska data.

- The EXXON equation overestimates generated emissions for the API data by a factor of two and underestimates emissions for the Alyeska data by a factor of seven.

- Using an adjusted TVP does give more accurate results for generated emissions for the Alyeska data.

Figure 5-3 compares the average total measured emissions with the calculated total emissions for the three equations and the API equation with adjusted TVP. The following conclusions can be drawn from this figure:

- The API equation comes closest to approximating the measured emissions for the API data set. However, the API equation underestimates emissions for the Alyeska data set.

- The ARCO equation overestimates (by a factor of three) the emissions for the API data. However, the ARCO equation does an excellent job of predicting the total emissions for the Alyeska data.

- The EXXON equation overestimates (by a factor of two) the emissions from the API data set and underestimates (by 40 percent) emissions from the Alyeska data set.

Since both the API and ARCO equations were correlated based on API and Alyeska data sets, it is expected that they would closely approximate their respective data sets. However, there appear to be factors that are causing the large difference in the emission between the Alyeska and API data. Section 6 discusses some of the factors that impact these emissions.

TABLE 5-1
CRUDE OIL LOADING: DATABASE DESCRIPTION(a)

| Test Number | Test Date | Tanker Name | (b) Tanker Category | Tanker Dead Weight (Mtons) | Crude Volume (MBbl) | (c) Test Location | Tanker/ Barge | (d) Tanker/ Compartment Emissions | Reference Number |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Feb-24-90 | OMI COLUMBIA | 1 | 135 | 848 | ALYESKA | TANKER | Tanker | 14 |
| 2 | Feb-25-90 | EXXON NORTH SLOPE | 1 | 165 | 1016 | ALYESKA | TANKER | Tanker | 15 |
| 3 | Mar-2-90 | ARCO SPIRIT | 1 | 265 | 1795 | ALYESKA | TANKER | Tanker | 20 |
| 4 | Mar-7-90 | ARCO TEXAS | 1 | 90 | 611 | ALYESKA | TANKER | Tanker | 24 |
| 5 | Mar-15-90 | GLACIER BAY | 1 | 80 | 555 | ALYESKA | TANKER | Tanker | 27 |
| 6 | Mar-17-90 | ANTIGUN PASS | 1 | 165 | 1058 | ALYESKA | TANKER | Tanker | 31 |
| 7 | Mar-19-90 | MOBIL ARCTIC | 1 | 120 | 828 | ALYESKA | TANKER | Tanker | 32 |
| 8 | Mar-28-90 | ARCO TEXAS | 1 | 90 | 612 | ALYESKA | TANKER | Tanker | 40 |
| 9 | Apr-1-90 | ARCO FAIRBANKS | 1 | 120 | 823 | ALYESKA | TANKER | Tanker | 42 |
| 10 | Apr-14-90 | ADMIRALTY BAY | 1 | 80 | 546 | ALYESKA | TANKER | Tanker | 47 |
| 11 | Apr-19-90 | ARCO FAIRBANKS | 1 | 120 | 848 | ALYESKA | TANKER | Tanker | 51 |
| 12 | Apr-21-90 | KEYSTONE CANYON | 3 | 165 | 1159 | ALYESKA | TANKER | Tanker | 53 |
| 13 | Apr-24-90 | MOBIL ARCTIC | 1 | 120 | 659 | ALYESKA | TANKER | Tanker | 57 |
| 14 | Apr-29-90 | OMI COLUMBIA | 1 | 135 | 807 | ALYESKA | TANKER | Tanker | 60 |
| 15 | Apr-29-90 | ADMIRALTY BAY | 1 | 80 | 565 | ALYESKA | TANKER | Tanker | 61 |
| 16 | Apr-30-90 | ARCO FAIRBANKS | 1 | 120 | 841 | ALYESKA | TANKER | Tanker | 63 |
| 17 | May-4-90 | ARCO PRUDHOE BAY | 1 | 75 | 493 | ALYESKA | TANKER | Tanker | 66 |
| 18 | May-8-90 | ADMIRALTY BAY | 1 | 80 | 568 | ALYESKA | TANKER | Tanker | 70 |
| 19 | May-20-90 | ARCO ANCHORAGE | 1 | 120 | 842 | ALYESKA | TANKER | Tanker | 73 |
| 20 | Jun-17-90 | ASPEN | 1 | 80 | 563 | ALYESKA | TANKER | Tanker | 76 |
| 21 | Jun-20-90 | EXXON BENICIA | 1 | 165 | 1033 | ALYESKA | TANKER | Tanker | 79 |
| 22 | Mar-2-90 | GLACIER BAY | 1 | 80 | 533 | ALYESKA | TANKER | Tanker | 81 |
| 23 | Apr-22-90 | ARCO CALIFORNIA | 1 | 190 | 1235 | ALYESKA | TANKER | Tanker | 55 |
| 24 | Feb-27-90 | ANTIGUN PASS | 1 | 165 | 1040 | ALYESKA | TANKER | Tanker | 16 |
| 25 | Apr-2-90 | THOMPSON PASS | 1 | 165 | 1180 | ALYESKA | TANKER | Tanker | 44 |
| 26 | Sep-5-76 | EXXON NEWARK | 4 | 28 | 70.04 | LOWER 48 | TANKER | Compartment | A-1-1 |
| 27 | Sep-11-76 | EXXON NEWARK | 1 | 28 | 57.081 | LOWER 48 | TANKER | Compartment | A-2-2 |
| 28 | Sep-11-76 | EXXON NEWARK | 4 | 28 | 23.754 | LOWER 48 | TANKER | Compartment | A-2-3 |
| 29 | Nov-21-76 | EXXON NEWARK | 3 | 28 | 32.407 | LOWER 48 | TANKER | Compartment | A-3-4 |
| 30 | Nov-21-76 | EXXON NEWARK | 3 | 28 | 11.782 | LOWER 48 | TANKER | Compartment | A-3-5 |

NOTES:

(a) Data for this comparison consists of selected data points from the Alyeska emission factor study and the Chevron/Ventury study.

(b) Category 1 – Tanker prior cargo was volatile, Compartment was uncleaned.
Category 2 – Tanker prior cargo was volatile, Compartment was ballasted.
Category 3 – Tanker prior cargo was volatile, Compartment was cleaned.
Category 4 – Tanker prior cargo was volatile, Compartment was gas freed.

(c) Test locations: Alyeska-Valdez Terminal, Alaska. Lower 48-Ventura County, California.

(d) T = Emissions were measured for entire tanker.
C = Emissions were measured for selected compartments.

NR = Not Recorded

TABLE 5-1
CRUDE OIL LOADING: DATABASE DESCRIPTION(a)

| Test Number | Test Date | Tanker Name | (b) Tanker Category | Tanker Dead Weight (Mtons) | Crude Volume (MBbl) | (c) Test Location | Tanker/ Barge | (d) Tanker/ Compartment Emissions | Reference Number |
|---|---|---|---|---|---|---|---|---|---|
| 31 | Nov-21-76 | EXXON NEWARK | 1 | 28 | 59.472 | LOWER 48 | TANKER | Compartment | A-3-6 |
| 32 | Oct-7-76 | SS LION OF CA | 4 | 17 | 35.906 | LOWER 48 | TANKER | Compartment | A-4-7 |
| 33 | Oct-7-76 | SS LION OF CA | 4 | 17 | 25.017 | LOWER 48 | TANKER | Compartment | A-4-8 |
| 34 | Oct-13-76 | SS LION OF CA | 4 | 17 | 17.42 | LOWER 48 | TANKER | Compartment | A-5-10 |
| 35 | Oct-13-76 | SS LION OF CA | 4 | 17 | 52.95 | LOWER 48 | TANKER | Compartment | A-5-9 |
| 36 | Jan-15-77 | SS LION OF CA | 4 | 17 | 56.03 | LOWER 48 | TANKER | Compartment | A-6-11 |
| 37 | Jan-15-77 | SS LION OF CA | 2 | 17 | 4.26 | LOWER 48 | TANKER | Compartment | A-6-12 |
| 38 | Jan-15-77 | SS LION OF CA | 4 | 17 | 3.84 | LOWER 48 | TANKER | Compartment | A-6-13 |
| 39 | Aug-19-76 | CHEVRON OREGON | 4 | 35 | 48.129 | LOWER 48 | TANKER | Compartment | A-7-14 |
| 40 | Dec-16-76 | CHEVRON OREGON | 4 | 35 | 31.437 | LOWER 48 | TANKER | Compartment | A-8-15 |
| 41 | Dec-16-76 | CHEVRON OREGON | 1 | 35 | 17.092 | LOWER 48 | TANKER | Compartment | A-8-16 |
| 42 | NR | NR | 4 | NR | NR | LOWER 48 | TANKER | Compartment | INIT W |
| 43 | NR | MOBILOIL | 4 | 30 | 114 | LOWER 48 | TANKER | Compartment | M 8-31 |

NOTES:

(a) Data for this comparison consists of selected data points from the Alyeska emission factor study and the Chevron/Ventury study.

(b) Category 1 – Tanker prior cargo was volatile, Compartment was uncleaned.
Category 2 – Tanker prior cargo was volatile, Compartment was ballasted.
Category 3 – Tanker prior cargo was volatile, Compartment was cleaned.
Category 4 – Tanker prior cargo was volatile, Compartment was gas freed.

(c) Test locations: Alyeska-Valdez Terminal, Alaska. Lower 48-Ventura County, California.

(d) T = Emissions were measured for entire tanker.
C = Emissions were measured for selected compartments.

NR = Not Recorded

TABLE 5-2
CRUDE OIL LOADING EMISSIONS:
ARRIVAL, GENERATED AND TOTAL MEASURED VALUES

| Test Number | Test Database | Measured Arrival Lbs HC/Mgal | Measured Generated lbs HC/Mgal | Measured Total Lbs HC/Mgal |
|---|---|---|---|---|
| 1 | Alyeska | 2.00 | 0.48 | 2.48 |
| 2 | Alyeska | 1.89 | 3.20 | 5.10 |
| 3 | Alyeska | 0.39 | 3.04 | 3.43 |
| 4 | Alyeska | 1.07 | 3.24 | 4.31 |
| 5 | Alyeska | 1.84 | 2.70 | 4.54 |
| 6 | Alyeska | 0.27 | 3.60 | 3.88 |
| 7 | Alyeska | 1.29 | 2.89 | 4.17 |
| 8 | Alyeska | 0.74 | 0.95 | 1.70 |
| 9 | Alyeska | 0.46 | 1.02 | 1.47 |
| 10 | Alyeska | 1.73 | 2.46 | 4.19 |
| 11 | Alyeska | 0.42 | 1.87 | 2.28 |
| 12 | Alyeska | 0.10 | 3.16 | 3.26 |
| 13 | Alyeska | 1.19 | 1.15 | 2.34 |
| 14 | Alyeska | 0.94 | 1.55 | 2.48 |
| 15 | Alyeska | 0.91 | 2.70 | 3.62 |
| 16 | Alyeska | 0.25 | 2.24 | 2.49 |
| 17 | Alyeska | 0.54 | 2.59 | 3.13 |
| 18 | Alyeska | 0.97 | 2.55 | 3.52 |
| 19 | Alyeska | 0.38 | 1.02 | 1.40 |
| 20 | Alyeska | 0.88 | 2.55 | 3.43 |
| 21 | Alyeska | 0.78 | 3.45 | 4.22 |
| 22 | Alyeska | 0.96 | 1.35 | 2.32 |
| 23 | Alyeska | 0.61 | 1.95 | 2.56 |
| 24 | Alyeska | 0.18 | 4.18 | 4.36 |
| 25 | Alyeska | 0.57 | 4.28 | 4.85 |
| 26 | Lower 48 | 0.32 | 0.30 | 0.62 |
| 27 | Lower 48 | 0.91 | 0.34 | 1.25 |
| 28 | Lower 48 | 0.05 | 0.65 | 0.70 |
| 29 | Lower 48 | 1.53 | 0.19 | 1.72 |
| 30 | Lower 48 | 1.54 | 0.22 | 1.76 |
| 31 | Lower 48 | 1.92 | 0.06 | 1.98 |
| 32 | Lower 48 | 0.69 | 0.53 | 1.22 |
| 33 | Lower 48 | 0.24 | 0.45 | 0.69 |
| 34 | Lower 48 | 0.13 | 0.84 | 0.97 |
| 35 | Lower 48 | 0.34 | 0.53 | 0.87 |
| 36 | Lower 48 | 0.12 | 0.20 | 0.32 |
| 37 | Lower 48 | 0.81 | 0.21 | 1.02 |
| 38 | Lower 48 | 0.52 | 0.16 | 0.68 |
| 39 | Lower 48 | 0.20 | 0.00 | 0.20 |
| 40 | Lower 48 | 0.34 | 0.04 | 0.38 |
| 41 | Lower 48 | 1.08 | 0.00 | 1.08 |
| ALYESKA AVERAGE: | | 0.85 | 2.41 | 3.26 |
| API AVERAGE: | | 0.67 | 0.30 | 0.97 |

'ABLE 5-3
:RUDE OIL LOADING EMISSIONS
\PI 2514A EQUATION: CALCULATED EMISSIONS COMPARISON WITH MEASURED VALUES

| Test Number | (a) Location (Tanker/ Barge) | Tanker ead Weigh (Mtons) | Reid Vapor Pressure (psia) | Crude Volume (MBbl) | Crude Temp (F) | (b) True Vapor Pressure (TVP) | Vapor Temp (F) | Vapor Temp (R) | Vapor Growth Factor | Average Vapor MW (lb/lbmol) | Arrival Emission Factor (Ea) (lb/1000gal) | Generated Emission Factor (Eg) (lb/1000gal) | API Calculated Emissions Ea+Eg | Measured Emissions (lb/1000gal) | (c) Percent Difference (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A(T) | 135 | 4.7 | 848 | 67.5 | 3.1 | 50 | 510 | 1.02 | 55.8 | 0.86 | 0.194 | 1.054 | 2.48 | -57.4 |
| 2 | A(T) | 165 | 5.3 | 1016 | 101.9 | 6.5 | 64 | 524 | 1.02 | 62 | 0.86 | 0.542 | 1.402 | 5.09 | -72.5 |
| 3 | A(T) | 265 | 5.4 | 1795 | 98.7 | 6.3 | 47 | 507 | 1.02 | 63.5 | 0.86 | 0.553 | 1.413 | 3.43 | -58.8 |
| 4 | A(T) | 90 | 5.1 | 611 | 106 | 6.6 | 61 | 521 | 1.02 | 59.3 | 0.86 | 0.531 | 1.391 | 4.31 | -67.7 |
| 5 | A(T) | 80 | 5.8 | 555 | 105.7 | 7.8 | 63 | 523 | 1.02 | 58.2 | 0.86 | 0.629 | 1.489 | 4.54 | -67.2 |
| 6 | A(T) | 165 | 5.3 | 1058 | 103.6 | 7 | 73 | 533 | 1.02 | 59.5 | 0.86 | 0.557 | 1.417 | 3.88 | -63.4 |
| 7 | A(T) | 120 | 5.7 | 828 | 110.7 | 8.1 | 63 | 523 | 1.02 | 62.2 | 0.86 | 0.702 | 1.562 | 4.18 | -62.6 |
| 8 | A(T) | 90 | 4.8 | 612 | 65.4 | 3 | 48 | 508 | 1.02 | 59.9 | 0.86 | 0.199 | 1.059 | 1.70 | -37.6 |
| 9 | A(T) | 120 | 5.1 | 823 | 66.6 | 3.2 | 47 | 507 | 1.02 | 59 | 0.86 | 0.216 | 1.076 | 1.48 | -27.1 |
| 10 | A(T) | 80 | 4.8 | 546 | 109.1 | 4.6 | 62 | 522 | 1.02 | 58.8 | 0.86 | 0.339 | 1.199 | 4.19 | -71.4 |
| 11 | A(T) | 120 | 5.2 | 848 | 83 | 4.5 | 51 | 511 | 1.02 | 58.6 | 0.86 | 0.336 | 1.196 | 2.28 | -47.6 |
| 12 | A(T) | 165 | 5.1 | 1159 | 105.2 | 6.5 | 75 | 535 | 1.02 | 54.9 | 0.33 | 0.470 | 0.800 | 3.26 | -75.5 |
| 13 | A(T) | 120 | 5.7 | 659 | 104.2 | 7.2 | 65 | 525 | 1.02 | 59.2 | 0.86 | 0.582 | 1.442 | 2.34 | -38.4 |
| 14 | A(T) | 135 | 5.2 | 807 | 101.6 | 6.3 | 69 | 529 | 1.02 | 58.07 | 0.86 | 0.485 | 1.345 | 2.48 | -45.9 |
| 15 | A(T) | 80 | 5.5 | 565 | 104.5 | 7.1 | 71 | 531 | 1.02 | 55.9 | 0.86 | 0.534 | 1.394 | 3.62 | -61.4 |
| 16 | A(T) | 120 | 5.7 | 841 | 103.3 | 7 | 67 | 527 | 1.02 | 58 | 0.86 | 0.549 | 1.409 | 2.49 | -43.4 |
| 17 | A(T) | 75 | 6.4 | 493 | 101.8 | 8 | 59 | 519 | 1.02 | 61.7 | 0.86 | 0.692 | 1.552 | 3.13 | -50.4 |
| 18 | A(T) | 80 | 6.1 | 568 | 100.6 | 7.5 | 62 | 522 | 1.02 | 58.8 | 0.86 | 0.609 | 1.469 | 3.52 | -58.3 |
| 19 | A(T) | 120 | 5 | 842 | 80.2 | 4.1 | 61 | 521 | 1.02 | 58 | 0.86 | 0.289 | 1.149 | 1.41 | -18.4 |
| 20 | A(T) | 80 | 5.4 | 563 | 87.3 | 5 | 69 | 529 | 1.02 | 58 | 0.86 | 0.366 | 1.226 | 3.43 | -64.3 |

NOTES:

(a) A(T)=Alyeska Database(Tanker) L48(T)=Lower 48 States Database(Tanker)

(b) API Nomograph

(c) %-Difference = (Calculated - Measured)/Measured * 100

TABLE 5-3

CRUDE OIL LOADING EMISSIONS

API 2514A EQUATION: CALCULATED EMISSIONS COMPARISON WITH MEASURED VALUES

| Test Number | (a) Location (Tanker/ Barge) | Tanker ead Weigh (Mtons) | Reid Vapor Pressure (psia) | Crude Volume (MBbl) | Crude Temp (F) | (b) True Vapor Pressure (TVP) | Vapor Temp (F) | Vapor Temp (R) | Vapor Growth Factor | Average Vapor MW (lb/lbmol) | Arrival Emission Factor (Ea) (lb/1000gal) | Generated Emission Factor (Eg) (lb/1000gal) | API Calculated Emissions Ea+Eg | Measured Emissions (lb/1000gal) | (c) Percent Difference (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | A(T) | 165 | 5.1 | 1033 | 86.6 | 4.7 | 64 | 524 | 1.02 | 58 | 0.86 | 0.342 | 1.202 | 4.22 | -71.5 |
| 22 | A(T) | 80 | na | 533 | 61 | 5 | 60 | 520 | 1.02 | 58 | 0.86 | 0.373 | 1.233 | 2.31 | -46.7 |
| 23 | A(T) | 190 | 4.8 | 1235 | 104.3 | 6 | 69 | 529 | 1.02 | 61.6 | 0.86 | 0.485 | 1.345 | 3.67 | -63.3 |
| 24 | A(T) | 165 | 5.1 | 1040 | 99.5 | 6 | 61 | 521 | 1.02 | 58 | 0.86 | 0.464 | 1.324 | 5.50 | -75.9 |
| 25 | A(T) | 165 | 5.6 | 1180 | 102 | 6.9 | 55 | 515 | 1.02 | 56 | 0.86 | 0.534 | 1.394 | 4.85 | -71.2 |
| 26 | L48(T) | 28 | 5.2 | 70.04 | 75 | 3.8 | 78 | 538 | 1.02 | 58 | 0.33 | 0.253 | 0.583 | 0.62 | -5.9 |
| 27 | L48(T) | 28 | 5.2 | 57.081 | 83 | 4.4 | 73 | 533 | 1.02 | 58 | 0.86 | 0.310 | 1.170 | 1.25 | -6.4 |
| 28 | L48(T) | 28 | 5.2 | 23.754 | 83 | 4.4 | 72 | 532 | 1.02 | 53 | 0.33 | 0.310 | 0.640 | 0.70 | -8.5 |
| 29 | L48(T) | 28 | 5.2 | 32.407 | 78 | 4 | 64 | 524 | 1.02 | 58 | 0.33 | 0.278 | 0.608 | 1.72 | -64.6 |
| 30 | L48(T) | 28 | 5.2 | 11.782 | 78 | 4 | 64 | 524 | 1.02 | 58 | 0.33 | 0.278 | 0.608 | 1.72 | -64.6 |
| 31 | L48(T) | 28 | 5.2 | 59.472 | 78 | 4 | 66 | 526 | 1.02 | 58 | 0.86 | 0.277 | 1.137 | 1.98 | -42.6 |
| 32 | L48(T) | 17 | 7 | 35.906 | 80 | 6 | 67 | 527 | 1.02 | 58 | 0.33 | 0.459 | 0.789 | 1.22 | -35.4 |
| 33 | L48(T) | 17 | 7 | 25.017 | 80 | 6 | 67 | 527 | 1.02 | 58 | 0.33 | 0.459 | 0.789 | 0.69 | 14.3 |
| 34 | L48(T) | 17 | 7 | 17.42 | 83 | 6.5 | 66 | 526 | 1.02 | 58 | 0.33 | 0.505 | 0.835 | 0.97 | -13.9 |
| 35 | L48(T) | 17 | 7 | 52.95 | 83 | 6.5 | 68 | 528 | 1.02 | 58 | 0.33 | 0.503 | 0.833 | 0.87 | -4.2 |
| 36 | L48(T) | 17 | 5.2 | 56.03 | 70 | 3.5 | 65 | 525 | 1.02 | 58 | 0.33 | 0.232 | 0.562 | 0.32 | 75.7 |
| 37 | L48(T) | 17 | 5.2 | 4.26 | 70 | 3.5 | 62 | 522 | 1.02 | 58 | 0.46 | 0.234 | 0.694 | 1.02 | -32.0 |
| 38 | L48(T) | 17 | 5.2 | 3.84 | 70 | 3.5 | 59 | 519 | 1.02 | 58 | 0.33 | 0.235 | 0.565 | 0.68 | -16.9 |
| 39 | L48(T) | 35 | 7 | 48.129 | 83 | 0 | 90 | 550 | 1.02 | 58 | 0.33 | 0.000 | 0.330 | 0.2 | 65.0 |
| 40 | L48(T) | 35 | 0.3 | 31.437 | 113 | 0 |  | 530 | 1.02 | 58 | 0.33 | 0.000 | 0.330 | 0.38 | -13.2 |
| 41 | L48(T) | 35 | 0.3 | 17.092 | 120 | 0 | 78 | 538 | 1.02 | 58 | 0.86 | 0.000 | 0.860 | 1.08 | -20.4 |
| 42 | L48(T) |  | 0.2 |  | 112 | 1 | 70 | 530 | 1.02 | 58 | 0.33 | 0.004 | 0.334 | 0.60 | -44.3 |
| 43 | L48(T) | 30 | 6.1 | 114 | 68 | 4.8 | 68 | 528 | 1.02 | 58 | 0.33 | 0.349 | 0.679 | 0.98 | -30.7 |
|  |  |  |  |  |  |  |  |  |  |  |  | AVERAGES: | 1.04 | 2.34 | -38.76 |
|  |  |  |  |  |  |  |  |  |  |  |  | ABSOLUTE AVERAGE: |  |  | 45.97 |

NOTES:

(a) A(T)=Alyeska Database(Tanker) L48(T)=Lower 48 States Database(Tanker)

(b) API Nomograph

(c) %-Difference = (Calculated - Measured)/Measured * 100



API PUBL*2524 92 0732290 0503582 985

TABLE 5-4

CRUDE OIL LOADING EMISSIONS

ARCO PLANO CALCULATED EMISSIONS EQUATION COMPARISON WITH MEASURED VALUES

| Test Number | (a) Location (Tanker/ Barge) | Tanker Class (MDWT) | Tanker Factor | Temp (F) | Tanker % Full | Surface Area (ft2) | Load Time (min) | Volume Loaded (MMBbls) | (b) ppbHC | yHC Arrival | (b) yHCsat | Ton HC Calculated | (lb/Mgal) Calculated | (lb/Mgal) Measured | (c) % Difference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A(T) | 135 | 0.833651 | 67.5 | 81.23 | 80100 | 622 | 0.848 | 0.3846 | 0.0564 | 0.3592 | 33.74 | 1.89 | 2.48 | -23.50 |
| 2 | A(T) | 165 | 1.738317 | 101.9 | 85.49 | 85200 | 693 | 1.016 | 0.39813 | 0.0468 | 0.3576 | 93.70 | 4.39 | 5.09 | -13.80 |
| 3 | A(T) | 265 | 1.060743 | 98.7 | 89.03 | 130829 | 1155 | 1.795 | 0.42887 | 0.0160 | 0.3527 | 125.09 | 3.32 | 3.43 | -3.26 |
| 4 | A(T) | 90 | 0.917953 | 106 | 98.18 | 56806 | 753 | 0.611 | 0.3922 | 0.0478 | 0.3563 | 45.50 | 3.55 | 4.31 | -17.71 |
| 5 | A(T) | 80 | 0.887232 | 105.7 | 92.8 | 59500 | 769 | 0.555 | 0.397 | 0.0471 | 0.3572 | 44.45 | 3.81 | 4.54 | -15.98 |
| 6 | A(T) | 165 | 1.738317 | 103.6 | 88.85 | 85200 | 658 | 1.058 | 0.4345 | 0.0102 | 0.3517 | 89.93 | 4.05 | 3.88 | 4.44 |
| 7 | A(T) | 120 | 1 | 110.7 | 88.96 | 73777 | 768 | 0.828 | 0.3866 | 0.0576 | 0.3574 | 67.03 | 3.86 | 4.18 | -7.67 |
| 8 | A(T) | 90 | 0.917953 | 65.4 | 96.48 | 56806 | 714 | 0.612 | 0.4093 | 0.0324 | 0.3543 | 21.75 | 1.69 | 1.70 | -0.25 |
| 9 | A(T) | 120 | 1 | 66.6 | 87.6 | 77144 | 570 | 0.823 | 0.425 | 0.0208 | 0.3536 | 23.53 | 1.36 | 1.48 | -7.71 |
| 10 | A(T) | 80 | 0.887232 | 109.1 | 91.46 | 59500 | 746 | 0.546 | 0.3249 | 0.0750 | 0.3371 | 43.33 | 3.78 | 4.19 | -9.74 |
| 11 | A(T) | 120 | 1 | 83 | 90.87 | 77144 | 573 | 0.848 | 0.4278 | 0.0198 | 0.3535 | 32.67 | 1.83 | 2.28 | -19.54 |
| 12 | A(T) | 165 | 1.738317 | 105.2 | 97.32 | 85200 | 790 | 1.159 | 0.3948 | 0.0038 | 0.3263 | 98.45 | 4.05 | 3.26 | 24.00 |
| 13 | A(T) | 120 | 1 | 104.2 | 71.63 | 73777 | 511 | 0.659 | 0.341 | 0.0555 | 0.3332 | 38.01 | 2.75 | 2.34 | 17.30 |
| 14 | A(T) | 135 | 0.833651 | 101.6 | 87.76 | 80100 | 579 | 0.807 | 0.352 | 0.0460 | 0.3327 | 40.69 | 2.40 | 2.48 | -3.35 |
| 15 | A(T) | 80 | 0.887232 | 104.5 | 94.5 | 59500 | 890 | 0.565 | 0.3528 | 0.0490 | 0.3346 | 43.94 | 3.70 | 3.62 | 2.42 |
| 16 | A(T) | 120 | 1 | 103.3 | 90.92 | 77144 | 584 | 0.841 | 0.38739 | 0.0115 | 0.3274 | 39.30 | 2.23 | 2.49 | -10.67 |
| 17 | A(T) | 75 | 0.804015 | 101.8 | 89.64 | 54400 | 545 | 0.493 | 0.4707 | 0.0024 | 0.3761 | 24.63 | 2.38 | 3.13 | -23.98 |
| 18 | A(T) | 80 | 0.887232 | 100.6 | 94.68 | 59500 | 784 | 0.568 | 0.4495 | 0.0468 | 0.3802 | 47.73 | 4.00 | 3.52 | 13.62 |
| 19 | A(T) | 120 | 1 | 80.2 | 90.12 | 77144 | 584 | 0.842 | 0.38002 | 0.0171 | 0.3279 | 27.03 | 1.53 | 1.40 | 9.17 |
| 20 | A(T) | 80 | 0.887232 | 87.3 | 93.45 | 59500 | 791 | 0.563 | 0.40086 | 0.0457 | 0.3574 | 35.05 | 2.96 | 3.43 | -13.68 |

NOTES:

(a) A(T) = Alyeska database(Tanker) L48(T) = Lower 48 state database(Tanker)

(b) Data was estimated from average flash calculation values in ARCO model description.

TABLE 5-4

CRUDE OIL LOADING EMISSIONS

ARCO PLANO CALCULATED EMISSIONS EQUATION COMPARISON WITH MEASURED VALUES

| Test Number | (a) Location (Tanker/ Barge) | Tanker Class (MDWT) | Tanker Factor | Temp (F) | Tanker % Full | Surface Area (ft2) | Load Time (min) | Volume Loaded (MMBbls) | (b) ppbHC | yHC Arrival | (b) yHCsat | Ton HC Calculated | (lb/Mgal) Calculated | (lb/Mgal) Measured | (c) % Difference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | A(T) | 165 | 1.738317 | 86.6 | 86.11 | 85200 | 712 | 1.033 | 0.40756 | 0.0395 | 0.3565 | 74.61 | 3.44 | 4.22 | -18.55 |
| 23 | A(T) | 190 | 0.615908 | 104.3 | 93.4 | 110946 | 825 | 1.235 | 0.3689 | 0.0271 | 0.3294 | 53.61 | 2.07 | 2.56 | -19.14 |
| 24 | A(T) | 165 | 1.738317 | 99.5 | 87.59 | 85200 | 655 | 1.04 | 0.38027 | 0.0080 | 0.3591 | 69.76 | 3.19 | 4.35 | -26.64 |
| 25 | A(T) | 165 | 1.738317 | 102 | 99 | 85200 | 794 | 1.18 | 0.4201 | 0.0240 | 0.3535 | 109.65 | 4.42 | 4.85 | -8.70 |
| 26 | L48(T) | 28 | 0.804015 | 76 | 97.24 | 9359 | 1155 | 0.07004 | 0.405 | 0.0140 | 0.3550 | 5.13 | 3.49 | 0.62 | 462.43 |
| 27 | L48(T) | 28 | 0.804015 | 83 | 94.99 | 8153 | 1050 | 0.057018 | 0.405 | 0.0450 | 0.3550 | 5.44 | 4.54 | 1.25 | 263.36 |
| 28 | L48(T) | 28 | 0.804015 | 83 | 96.7 | 3245 | 1050 | 0.023754 | 0.405 | 0.0030 | 0.3550 | 2.03 | 4.08 | 0.7 | 482.61 |
| 29 | L48(T) | 28 | 0.804015 | 78 | 96.7 | 4508 | 1185 | 0.032407 | 0.405 | 0.0730 | 0.3550 | 3.47 | 5.10 | 1.72 | 196.61 |
| 31 | L48(T) | 28 | 0.804015 | 78 | 96.6 | 8120 | 1185 | 0.059472 | 0.405 | 0.0910 | 0.3550 | 6.39 | 5.12 | 1.98 | 158.56 |
| 32 | L48(T) | 17 | 0.804015 | 80 | 96.7 | 5308 | 600 | 0.035906 | 0.405 | 0.03 | 0.3550 | 2.18 | 2.89 | 1.22 | 136.73 |
| 33 | L48(T) | 17 | 0.804015 | 80 | 96.6 | 3545 | 600 | 0.025017 | 0.405 | 0.01 | 0.3550 | 1.32 | 2.52 | 0.69 | 264.99 |
| 34 | L48(T) | 17 | 0.804015 | 83 | 97.4 | 2524 | 390 | 0.017427 | 0.405 | 0.0060 | 0.3550 | 0.71 | 1.93 | 0.97 | 98.71 |
| 35 | L48(T) | 17 | 0.804015 | 83 | 96.8 | 7709 | 585 | 0.052954 | 0.405 | 0.017 | 0.3550 | 2.93 | 2.64 | 0.87 | 203.26 |
| 36 | L48(T) | 17 | 0.804015 | 70 | 99 | 7992 | 630 | 0.05603 | 0.405 | 0.006 | 0.3550 | 2.20 | 1.87 | 0.32 | 485.29 |
| 37 | L48(T) | 17 | 0.804015 | 70 | 97.5 | 646 | 285 | 0.00426 | 0.405 | 0.038 | 0.3550 | 0.17 | 1.94 | 1.02 | 90.21 |
| 38 | L48(T) | 17 | 0.804015 | 70 | 97.9 | 577 | 210 | 0.00384 | 0.405 | 0.023 | 0.3550 | 0.11 | 1.37 | 0.68 | 101.65 |
| 39 | L48(T) | 35 | 0.804015 | 113 | 67.4 | 8433 | 360 | 0.048129 | 0.405 | 0.015 | 0.3550 | 3.05 | 3.02 | 0.2 | 1409.00 |
| 40 | L48(T) | 35 | 0.804015 | 117 | 88.2 | 4579 | 330 | 0.031437 | 0.405 | 0.0240 | 0.3550 | 2.10 | 3.18 | 0.38 | 736.22 |
| | | | | | | | | | | | AVERAGES: | | 3.06 | 2.42 | 129.39 |
| | | | | | | | | | | | ABSOLUTE AVERAGE: | | | | 142.22 |

NOTES:

(a) A(T) = Alyeska database(Tanker) L48(T) = Lower 48 state database(Tanker)

(b) Data was estimated from average flash calculation values in ARCO model description.

TABLE 5-5
CRUDE OIL LOADING EMISSIONS
EXXON EQUATION: CALCULATED EMISSIONS COMPARISON WITH MEASURED VALUES

| Test Number | (a) Location (Tanker/ Barge) | Tanker MDWT | TVP (psia) | Surface Area (ft2) | Volume Loaded (MMBbls) | Volume Loaded (cu ft.) | Unused Capacity (Mbbl) | Calculated Ullage (ft) | Ullage Correction (ft3/ft2-psia) | Cu. Ft. HC Calculated | Ton HC Calculated | (lb/Mgal) Calculated | (lb/Mgal) Measured | (b) % Difference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A(T) | 135 | 3.1 | 80100 | 0.848 | 4761497 | 196.75 | 13.8 | 0.29 | 398301 | 29.85 | 1.68 | 2.48 | -32.3 |
| 2 | A(T) | 165 | 6.5 | 85200 | 1.016 | 5704813 | 176.1 | 11.6 | 0.26 | 511765 | 38.35 | 1.80 | 5.09 | -64.7 |
| 3 | A(T) | 265 | 6.3 | 130829 | 1.795 | 10078877 | 225.48 | 9.7 | 0.26 | 888732 | 66.60 | 1.77 | 3.43 | -48.5 |
| 4 | A(T) | 90 | 6.6 | 56806 | 0.611 | 3430749 | 11.54 | 1.1 | 0.07 | 383187 | 28.71 | 2.24 | 4.31 | -48.1 |
| 5 | A(T) | 80 | 7.8 | 59500 | 0.555 | 3116310 | 43.86 | 4.1 | 0.17 | 337484 | 25.29 | 2.17 | 4.54 | -52.2 |
| 6 | A(T) | 165 | 7 | 85200 | 1.058 | 5940642 | 135.42 | 8.9 | 0.26 | 534891 | 40.08 | 1.80 | 3.88 | -53.4 |
| 7 | A(T) | 120 | 8.1 | 73777 | 0.828 | 4649198 | 105.61 | 8.0 | 0.25 | 437671 | 32.80 | 1.89 | 4.18 | -54.8 |
| 8 | A(T) | 90 | 3 | 56806 | 0.612 | 3436364 | 21.75 | 2.1 | 0.11 | 317514 | 23.79 | 1.85 | 1.70 | 9.1 |
| 9 | A(T) | 120 | 3.2 | 77144 | 0.823 | 4621123 | 116.85 | 8.5 | 0.25 | 396845 | 29.74 | 1.72 | 1.48 | 16.6 |
| 10 | A(T) | 80 | 4.6 | 59500 | 0.546 | 3065775 | 52.1 | 4.9 | 0.18 | 294528 | 22.07 | 1.92 | 4.19 | -54.0 |
| 11 | A(T) | 120 | 4.5 | 77144 | 0.848 | 4761497 | 86.06 | 6.3 | 0.23 | 426049 | 31.93 | 1.79 | 2.28 | -21.4 |
| 12 | A(T) | 165 | 6.5 | 85200 | 1.159 | 6507754 | 32.51 | 2.1 | 0.11 | 659070 | 49.39 | 2.03 | 3.26 | -37.8 |
| 13 | A(T) | 120 | 7.2 | 73777 | 0.659 | 3700267 | 265.9 | 20.2 | 0.32 | 317269 | 23.77 | 1.72 | 2.34 | -26.6 |
| 14 | A(T) | 135 | 6.3 | 80100 | 0.807 | 4531283 | 114.62 | 8.0 | 0.25 | 418012 | 31.32 | 1.85 | 2.48 | -25.6 |
| 15 | A(T) | 80 | 7.1 | 59500 | 0.565 | 3172460 | 33.56 | 3.2 | 0.15 | 342511 | 25.67 | 2.16 | 3.62 | -40.2 |
| 16 | A(T) | 120 | 7 | 77144 | 0.841 | 4722193 | 85.63 | 6.2 | 0.23 | 447976 | 33.57 | 1.90 | 2.49 | -23.7 |
| 17 | A(T) | 75 | 8 | 55500 | 0.493 | 2768182 | 58 | 5.9 | 0.23 | 279175 | 20.92 | 2.02 | 3.13 | -35.4 |
| 18 | A(T) | 80 | 7.5 | 59500 | 0.568 | 3189305 | 32.44 | 3.1 | 0.15 | 348857 | 26.14 | 2.19 | 3.52 | -37.8 |
| 19 | A(T) | 120 | 4.1 | 77144 | 0.842 | 4727807 | 93.15 | 6.8 | 0.236 | 417445 | 31.28 | 1.77 | 1.40 | 26.3 |
| 20 | A(T) | 80 | 5 | 59500 | 0.563 | 3161230 | 39.89 | 3.8 | 0.17 | 309423 | 23.19 | 1.96 | 3.43 | -42.9 |
| 21 | A(T) | 165 | 4.7 | 85200 | 1.033 | 5800267 | 168.67 | 11.1 | 0.27 | 500061 | 37.47 | 1.73 | 4.22 | -59.1 |
| 23 | A(T) | 190 | 6 | 110946 | 1.235 | 6934492 | 89.15 | 4.5 | 0.18 | 674581 | 50.55 | 1.95 | 2.56 | -23.8 |
| 24 | A(T) | 165 | 6 | 85200 | 1.04 | 5839572 | 150.64 | 9.9 | 0.26 | 518286 | 38.84 | 1.78 | 4.35 | -59.2 |
| 25 | A(T) | 165 | 6.9 | 85200 | 1.18 | 6625668 | 12.16 | 0.8 | 0.05 | 712296 | 53.38 | 2.15 | 4.85 | -55.6 |
| 26 | L(48) | 28 | 3.8 | 9359 | 0.07004 | 393273 | 1.99 | 1.2 | 0.07 | 41775 | 3.13 | 2.13 | 0.62 | 243.3 |

NOTES:
(a) A(T)=Alyeska database(tanker) L48(T)=Lower 48 state database(tanker)
(b) %-Difference = (Calculated - Measured)/Measured * 100%

TABLE 5-5

CRUDE OIL LOADING EMISSIONS

EXXON EQUATION: CALCULATED EMISSIONS COMPARISON WITH MEASURED VALUES

| Test Number | (a) Location (Tanker/ Barge) | Tanker MDWT | TVP (psia) | Surface Area (ft2) | Volume Loaded (MMBbls) | Volume Loaded (cu ft.) | Unused Capacity (Mbbl) | Calculated Ullage (ft) | Ullage Correction (ft3/ft2-psia) | Cu. Ft. HC Calculated | Ton HC Calculated | (lb/Mgal) Calculated | (lb/Mgal) Measured | (b) % Difference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | L(48) | 28 | 4.4 | 8153 | 0.057081 | 320508 | 3.01 | 2.1 | 0.11 | 34609 | 2.59 | 2.16 | 1.25 | 73.1 |
| 28 | L(48) | 28 | 4.4 | 3245 | 0.023754 | 133378 | 0.81 | 1.4 | 0.08 | 14668 | 1.10 | 2.20 | 0.70 | 214.8 |
| 29 | L(48) | 28 | 4 | 4508 | 0.032407 | 181964 | 1.11 | 1.4 | 0.08 | 19606 | 1.47 | 2.16 | 1.72 | 25.5 |
| 30 | L(48) | 28 | 4 | 8120 | 0.011782 | 66156 | 0.41 | 0.3 | 0.06 | 15036 | 1.13 | 4.55 | 1.72 | 164.8 |
| 32 | L(48) | 28 | 6 | 5308 | 0.035906 | 201611 | 1.23 | 1.3 | 0.15 | 22817 | 1.71 | 2.27 | 1.22 | 85.9 |
| 33 | L(48) | 17 | 6 | 3545 | 0.025017 | 140470 | 0.88 | 1.4 | 0.08 | 17193 | 1.29 | 2.45 | 0.69 | 255.4 |
| 34 | L(48) | 17 | 6.5 | 7709 | 0.05295 | 297313 | 1.75 | 1.3 | 0.08 | 37815 | 2.83 | 2.55 | 0.87 | 192.9 |
| 35 | L(48) | 17 | 6.5 | 2524 | 0.01742 | 97813 | 0.47 | 1.0 | 0.07 | 12583 | 0.94 | 2.58 | 0.97 | 165.7 |
| 36 | L(48) | 17 | 3.5 | 7992 | 0.05603 | 314607 | 0.57 | 0.4 | 0.06 | 33560 | 2.51 | 2.14 | 0.32 | 567.9 |
| 37 | L(48) | 17 | 3.5 | 646 | 0.00426 | 23920 | 0.11 | 0.9 | 0.06 | 2592 | 0.19 | 2.17 | 1.02 | 112.8 |
| 38 | L(48) | 17 | 3.5 | 577 | 0.00384 | 21561 | 0.08 | 0.8 | 0.06 | 2331 | 0.17 | 2.17 | 0.68 | 218.5 |
| 39 | L(48) | 17 | 0 | 8433 | 0.048129 | 270243 | 23.28 | 15.5 | 0.3 | 21619 | 1.62 | 1.60 | 0.2 | 701.4 |
| 40 | L(48) | 35 | 0 | 4579 | 0.031437 | 176518 | 4.21 | 5.2 | 0.2 | 14121 | 1.06 | 1.60 | 0.38 | 321.8 |
| | | | | | | | | | | | AVERAGE: | | | 65.8 |
| | | | | | | | | | | | ABSOLUTE AVERAGE: | | | 113.0 |

NOTES:

(a) A(T)=Alyeska database(tanker) L48(T)=Lower 48 state database(tanker)

(b) %-Difference = (Calculated - Measured)/Measured * 100%

TABLE 5-6
CRUDE OIL LOADING EMISSIONS
PREDICTED MODEL COMPARISONS (TOTAL EMISSIONS)

| Test Number | (a) Location (Tanker/ Barge) | API Calculated Emissions Ea+Eg | ARCO Calculated Emissions (lb/Mgal) | EXXON Calculated Emissions (lb/Mgal) | (b)API vs. EXXON (%) | (c)API vs. ARCO (%) | (d)EXXON vs. ARCO |
|---|---|---|---|---|---|---|---|
| 1 | A(T) | 1.054 | 1.89 | 1.68 | -37.1 | -44.4 | -11.5 |
| 2 | A(T) | 1.402 | 4.39 | 1.80 | -22.0 | -68.1 | -59.1 |
| 3 | A(T) | 1.413 | 3.32 | 1.77 | -20.0 | -57.4 | -46.8 |
| 4 | A(T) | 1.391 | 3.55 | 2.24 | -37.9 | -60.8 | -36.9 |
| 5 | A(T) | 1.489 | 3.81 | 2.17 | -31.4 | -61.0 | -43.1 |
| 6 | A(T) | 1.417 | 4.05 | 1.80 | -21.4 | -65.0 | -55.4 |
| 7 | A(T) | 1.562 | 3.86 | 1.89 | -17.2 | -59.5 | -51.1 |
| 8 | A(T) | 1.059 | 1.69 | 1.85 | -42.8 | -37.4 | 9.4 |
| 9 | A(T) | 1.076 | 1.36 | 1.72 | -37.5 | -21.0 | 26.4 |
| 10 | A(T) | 1.199 | 3.78 | 1.92 | -37.7 | -68.3 | -49.1 |
| 11 | A(T) | 1.196 | 1.83 | 1.79 | -33.3 | -34.8 | -2.3 |
| 12 | A(T) | 0.800 | 4.05 | 2.03 | -60.6 | -80.2 | -49.8 |
| 13 | A(T) | 1.442 | 2.75 | 1.72 | -16.1 | -47.5 | -37.4 |
| 14 | A(T) | 1.345 | 2.40 | 1.85 | -27.3 | -44.0 | -23.0 |
| 15 | A(T) | 1.394 | 3.70 | 2.16 | -35.5 | -62.3 | -41.6 |
| 16 | A(T) | 1.409 | 2.23 | 1.90 | -25.8 | -36.7 | -14.6 |
| 17 | A(T) | 1.552 | 2.38 | 2.02 | -23.2 | -34.8 | -15.1 |
| 18 | A(T) | 1.469 | 4.00 | 2.19 | -33.0 | -63.3 | -45.2 |
| 19 | A(T) | 1.149 | 1.53 | 1.77 | -35.0 | -24.8 | 15.7 |
| 20 | A(T) | 1.226 | 2.96 | 1.96 | -37.5 | -58.6 | -33.8 |
| 21 | A(T) | 1.202 | 3.44 | 1.73 | -30.4 | -65.0 | -49.8 |
| 22 | A(T) | 1.233 | | | | | |
| 23 | A(T) | 1.345 | 2.07 | 1.95 | -31.0 | -34.9 | -5.7 |
| 24 | A(T) | 1.324 | 3.19 | 1.78 | -25.6 | -58.6 | -44.3 |
| 25 | A(T) | 1.394 | 4.42 | 2.15 | -35.3 | -68.5 | -51.3 |
| 26 | L48(T) | 0.583 | 3.49 | 2.13 | -72.6 | -83.3 | -39.0 |
| 27 | L48(T) | 1.170 | 4.54 | 2.16 | -45.9 | -74.2 | -52.4 |
| 28 | L48(T) | 0.640 | 4.08 | 2.20 | -70.9 | -81.6 | -36.8 |
| 29 | L48(T) | 0.608 | 5.10 | 2.16 | -71.8 | -86.6 | -52.5 |
| 30 | L48(T) | 0.608 | | 4.55 | -86.6 | | |
| 31 | L48(T) | 1.137 | 5.12 | | | -77.7 | |
| 32 | L48(T) | 0.789 | 2.89 | 2.27 | -65.3 | -84.6 | -55.7 |
| 33 | L48(T) | 0.789 | 2.52 | 2.45 | -67.8 | -72.7 | -15.1 |
| 34 | L48(T) | 0.835 | 1.93 | 2.55 | -67.2 | -71.1 | -11.8 |
| 35 | L48(T) | 0.833 | 2.64 | 2.58 | -67.7 | -66.9 | 2.3 |

NOTES:
(a) A(T)=Alyeska test database(Tanker) L48(T)=Lower 48 state database(Tanker)
(b) %-Difference = (API - EXXON)/EXXON * 100
(c) %-Difference = (API - ARCO)/ARCO * 100
(d) %-Difference = (EXXON - ARCO)/ARCO * 100

TABLE 5-6
CRUDE OIL LOADING EMISSIONS
PREDICTED MODEL COMPARISONS (TOTAL EMISSIONS)

| Test Number | (a) Location (Tanker/ Barge) | API Calculated Emissions Ea+Eg | ARCO Calculated Emissions (lb/Mgal) | EXXON Calculated Emissions (lb/Mgal) | (b)API vs. EXXON (%) | (c)API vs. ARCO (%) | (d)EXXON vs. ARCO |
|---|---|---|---|---|---|---|---|
| 36 | L48(T) | 0.562 | 1.87 | 2.14 | -73.7 | -70.8 | 11.0 |
| 37 | L48(T) | 0.694 | 1.94 | 2.17 | -68.1 | -64.0 | 12.6 |
| 38 | L48(T) | 0.565 | 1.37 | 2.17 | -73.9 | -69.8 | 15.6 |
| 39 | L48(T) | 0.247 | 3.02 | 1.60 | -84.6 | -87.3 | -17.4 |
| 40 | L48(T) | 0.244 | 3.18 | 1.60 | -84.8 | -82.2 | 16.9 |
| 41 | L48(T) | 0.775 | 3.06 | | | -74.3 | |
| 42 | L48(T) | 0.334 | | | | | |
| 43 | L48(T) | 0.679 | | | | | |
| | | AVERAGE: | | | -46.2 | -61.6 | -25.3 |
| | | ABSOLUTE AVERAGE: | | | 45.0 | 60.1 | 30.9 |

NOTES:

(a) A(T)=Alyeska test database(Tanker) L48(T)=Lower 48 state database(Tanker)

(b) %-Difference = (API - EXXON)/EXXON * 100

(c) %-Difference = (API - ARCO)/ARCO * 100

(d) %-Difference = (EXXON - ARCO)/ARCO * 100

TABLE 5-7
CRUDE OIL LOADING EMISSIONS
PREDICTED MODEL COMPARISONS (ARRIVAL EMISSIONS)

| Test Number | API Equation: Arrival Emission Factor(Ea) (lb/Mgal) | Total Calculated Emissions (lb/Mgal) | Arrival Emissions % Total | ARCO Plano Equation: Arrival Emissions (lb/Mgal) | Total Calculated Emissions (lb/Mgal) | Arrival Emission % Total | EXXON Equation: Arrival Emissions (lb/Mgal) | Total Calculated Emissions (lb/Mgal) | Arrival Emission % Total |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.86 | 1.054 | 81.6% | 0.69 | 1.89 | 36.5% | 1.60 | 1.68 | 95.6% |
| 2 | 0.86 | 1.402 | 61.3% | 3.39 | 4.39 | 77.3% | 1.60 | 1.80 | 89.2% |
| 3 | 0.86 | 1.413 | 60.9% | 2.98 | 3.32 | 89.7% | 1.60 | 1.77 | 90.7% |
| 4 | 0.86 | 1.391 | 61.8% | 2.53 | 3.55 | 71.2% | 1.60 | 2.24 | 71.6% |
| 5 | 0.86 | 1.489 | 57.8% | 2.81 | 3.81 | 73.7% | 1.60 | 2.17 | 73.9% |
| 6 | 0.86 | 1.417 | 60.7% | 3.83 | 4.05 | 94.6% | 1.60 | 1.80 | 88.9% |
| 7 | 0.86 | 1.562 | 55.1% | 2.63 | 3.86 | 68.1% | 1.60 | 1.89 | 85.0% |
| 8 | 0.86 | 1.059 | 81.2% | 1.00 | 1.69 | 59.1% | 1.60 | 1.85 | 86.6% |
| 9 | 0.86 | 1.076 | 79.9% | 0.92 | 1.36 | 67.3% | 1.60 | 1.72 | 93.2% |
| 10 | 0.86 | 1.199 | 71.7% | 2.18 | 3.78 | 57.7% | 1.60 | 1.92 | 83.3% |
| 11 | 0.86 | 1.196 | 71.9% | 1.41 | 1.83 | 77.0% | 1.60 | 1.79 | 89.4% |
| 12 | 0.33 | 0.800 | 41.3% | 3.96 | 4.05 | 98.0% | 1.60 | 2.03 | 79.0% |
| 13 | 0.86 | 1.442 | 59.7% | 1.56 | 2.75 | 56.9% | 1.60 | 1.72 | 93.3% |
| 14 | 0.86 | 1.345 | 64.0% | 1.42 | 2.40 | 59.1% | 1.60 | 1.85 | 86.7% |
| 15 | 0.86 | 1.394 | 61.7% | 2.66 | 3.70 | 71.8% | 1.60 | 2.16 | 74.1% |
| 16 | 0.86 | 1.409 | 61.0% | 1.98 | 2.23 | 89.0% | 1.60 | 1.90 | 84.3% |
| 17 | 0.86 | 1.552 | 55.4% | 2.33 | 2.38 | 97.8% | 1.60 | 2.02 | 79.3% |
| 18 | 0.86 | 1.469 | 58.5% | 3.00 | 4.00 | 75.1% | 1.60 | 2.19 | 73.1% |
| 19 | 0.86 | 1.149 | 74.8% | 1.16 | 1.53 | 76.2% | 1.60 | 1.77 | 90.6% |
| 20 | 0.86 | 1.226 | 70.1% | 1.99 | 2.96 | 67.1% | 1.60 | 1.96 | 81.7% |
| 21 | 0.86 | 1.202 | 71.5% | 2.60 | 3.44 | 75.5% | 1.60 | 1.73 | 92.8% |
| 22 | 0.86 | 1.233 | 69.8% | | | | | | |
| 23 | 0.86 | 1.345 | 63.9% | 1.49 | 2.07 | 72.0% | 1.60 | 1.95 | 82.2% |
| 24 | 0.86 | 1.324 | 65.0% | 3.02 | 3.19 | 94.7% | 1.60 | 1.78 | 90.1% |
| 25 | 0.86 | 1.394 | 61.7% | 3.91 | 4.42 | 88.4% | 1.60 | 2.15 | 74.4% |

TABLE 5-7
CRUDE OIL LOADING EMISSIONS
PREDICTED MODEL COMPARISONS (ARRIVAL EMISSIONS)

| Test Number | API Equation: Arrival Emission Factor(Ea) (lb/Mgal) | API Equation: Total Calculated Emissions (lb/Mgal) | API Equation: Arrival Emissions % Total | ARCO Plano Equation: Arrival Emissions (lb/Mgal) | ARCO Plano Equation: Total Calculated Emissions (lb/Mgal) | ARCO Plano Equation: Arrival Emission % Total | EXXON Equation: Arrival Emissions (lb/Mgal) | EXXON Equation: Total Calculated Emissions (lb/Mgal) | EXXON Equation: Arrival Emission % Total |
|---|---|---|---|---|---|---|---|---|---|
| 26 | 0.33 | 0.583 | 56.6% | 0.30 | 3.49 | 8.6% | 1.60 | 2.13 | 75.3% |
| 27 | 0.86 | 1.170 | 73.5% | 0.96 | 4.54 | 21.1% | 1.60 | 2.16 | 74.1% |
| 28 | 0.33 | 0.640 | 51.5% | 0.06 | 4.08 | 1.6% | 1.60 | 2.20 | 72.7% |
| 29 | 0.33 | 0.608 | 54.2% | 1.56 | 5.10 | 30.5% | 1.60 | 2.16 | 74.2% |
| 30 | 0.33 | 0.608 | 54.2% | | | | 1.60 | 4.55 | 35.2% |
| 31 | 0.86 | 1.137 | 75.6% | 1.94 | 5.12 | 37.9% | 1.60 | 2.27 | 70.7% |
| 32 | 0.33 | 0.789 | 41.8% | 0.64 | 2.89 | 22.2% | 1.60 | 2.45 | 65.4% |
| 33 | 0.33 | 0.789 | 41.8% | 0.21 | 2.52 | 8.5% | 1.60 | 2.55 | 62.9% |
| 34 | 0.33 | 0.835 | 39.5% | 0.13 | 1.93 | 6.6% | 1.60 | 2.58 | 62.2% |
| 35 | 0.33 | 0.833 | 39.6% | 0.36 | 2.64 | 13.7% | 1.60 | 2.14 | 75.0% |
| 36 | 0.33 | 0.562 | 58.7% | 0.13 | 1.87 | 6.8% | 1.60 | 2.17 | 73.8% |
| 37 | 0.46 | 0.694 | 66.3% | 0.81 | 1.94 | 41.8% | 1.60 | 2.17 | 74.0% |
| 38 | 0.33 | 0.565 | 58.4% | 0.49 | 1.37 | 35.8% | 1.60 | 1.60 | 100.0% |
| 39 | 0.33 | 0.247 | 100.0% | 0.32 | 3.02 | 10.6% | 1.60 | 1.60 | 100.0% |
| 40 | 0.33 | 0.244 | 100.0% | 0.51 | 3.18 | 16.1% | | | |
| 41 | 0.86 | 0.775 | 100.0% | | | | | | |
| 42 | 0.33 | 0.334 | 98.8% | | | | | | |
| 43 | 0.33 | 0.679 | 48.6% | | | | | | |
| AVERAGES: | | | 64.7% | | | 54.10% | | | 80.12% |

TABLE 5-8
CRUDE OIL LOADING EMISSIONS
PREDICTED MODEL COMPARISONS (GENERATED EMISSIONS)

| Test Number | API Equation: Generated Emission Factor(Eg) (lb/Mgal) | API Equation: Total Calculated Emissions (lb/Mgal) | API Equation: Generated Emission % Total | ARCO Plano Equation: Generated Emission (lb/Mgal) | ARCO Plano Equation: Total Calculated Emissions (lb/Mgal) | ARCO Plano Equation: Generated Emission % Total | Exxon Equation: Generated Emission (lb/Mgal) | Exxon Equation: Total Calculated Emissions (lb/Mgal) | Exxon Equation: Generated Emission % Total |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.194 | 1.054 | 18.4% | 1.20 | 1.89 | 63.5% | 0.07 | 1.68 | 4.4% |
| 2 | 0.542 | 1.402 | 38.7% | 1.00 | 4.39 | 22.7% | 0.19 | 1.80 | 10.8% |
| 3 | 0.553 | 1.413 | 39.1% | 0.34 | 3.32 | 10.3% | 0.16 | 1.77 | 9.3% |
| 4 | 0.531 | 1.391 | 38.2% | 1.02 | 3.55 | 28.8% | 0.63 | 2.24 | 28.4% |
| 5 | 0.629 | 1.489 | 42.2% | 1.00 | 3.81 | 26.3% | 0.57 | 2.17 | 26.1% |
| 6 | 0.557 | 1.417 | 39.3% | 0.22 | 4.05 | 5.4% | 0.20 | 1.80 | 11.1% |
| 7 | 0.702 | 1.562 | 44.9% | 1.23 | 3.86 | 31.9% | 0.28 | 1.89 | 15.0% |
| 8 | 0.199 | 1.059 | 18.8% | 0.69 | 1.69 | 40.9% | 0.25 | 1.85 | 13.4% |
| 9 | 0.216 | 1.076 | 20.1% | 0.44 | 1.36 | 32.7% | 0.12 | 1.72 | 6.8% |
| 10 | 0.339 | 1.199 | 28.3% | 1.60 | 3.78 | 42.3% | 0.32 | 1.92 | 16.7% |
| 11 | 0.336 | 1.196 | 28.1% | 0.42 | 1.83 | 23.0% | 0.19 | 1.79 | 10.6% |
| 12 | 0.470 | 0.800 | 58.7% | 0.08 | 4.05 | 2.0% | 0.43 | 2.03 | 21.0% |
| 13 | 0.582 | 1.442 | 40.3% | 1.18 | 2.75 | 43.1% | 0.12 | 1.72 | 6.7% |
| 14 | 0.485 | 1.345 | 36.0% | 0.98 | 2.40 | 40.9% | 0.25 | 1.85 | 13.3% |
| 15 | 0.534 | 1.394 | 38.3% | 1.05 | 3.70 | 28.2% | 0.56 | 2.16 | 25.9% |
| 16 | 0.549 | 1.409 | 39.0% | 0.25 | 2.23 | 11.0% | 0.30 | 1.90 | 15.7% |
| 17 | 0.692 | 1.552 | 44.6% | 0.05 | 2.38 | 2.2% | 0.42 | 2.02 | 20.7% |
| 18 | 0.609 | 1.469 | 41.5% | 1.00 | 4.00 | 24.9% | 0.59 | 2.19 | 26.9% |
| 19 | 0.289 | 1.149 | 25.2% | 0.36 | 1.53 | 23.8% | 0.17 | 1.77 | 9.4% |
| 20 | 0.366 | 1.226 | 29.9% | 0.97 | 2.96 | 32.9% | 0.36 | 1.96 | 18.3% |
| 21 | 0.342 | 1.202 | 28.5% | 0.84 | 3.44 | 24.5% | 0.12 | 1.73 | 7.2% |
| 22 | 0.373 | 1.233 | 30.2% | | | | | | |
| 23 | 0.485 | 1.345 | 36.1% | 0.58 | 2.07 | 28.0% | 0.35 | 1.95 | 17.8% |
| 24 | 0.464 | 1.324 | 35.0% | 0.17 | 3.19 | 5.3% | 0.18 | 1.78 | 9.9% |
| 25 | 0.534 | 1.394 | 38.3% | 0.51 | 4.42 | 11.6% | 0.55 | 2.15 | 25.6% |

TABLE 5-8
CRUDE OIL LOADING EMISSIONS
PREDICTED MODEL COMPARISONS (GENERATED EMISSIONS)

| Test Number | API Equation: Generated Emission Factor(Eg) (lb/Mgal) | API Equation: Total Calculated Emissions (lb/Mgal) | API Equation: Generated Emission % Total | ARCO Plano Equation: Generated Emission (lb/Mgal) | ARCO Plano Equation: Total Calculated Emissions (lb/Mgal) | ARCO Plano Equation: Generated Emission % Total | Exxon Equation: Generated Emission (lb/Mgal) | Exxon Equation: Total Calculated Emissions (lb/Mgal) | Exxon Equation: Generated Emission % Total |
|---|---|---|---|---|---|---|---|---|---|
| 26 | 0.253 | 0.583 | 43.4% | 3.19 | 3.49 | 91.4% | 0.53 | 2.13 | 24.7% |
| 27 | 0.310 | 1.170 | 26.5% | 3.58 | 4.54 | 78.9% | 0.56 | 2.16 | 25.9% |
| 28 | 0.310 | 0.640 | 48.5% | 4.01 | 4.08 | 98.4% | 0.60 | 2.20 | 27.3% |
| 29 | 0.278 | 0.608 | 45.8% | 3.54 | 5.10 | 69.5% | 0.56 | 2.16 | 25.8% |
| 30 | 0.278 | 0.608 | 45.8% | | | | 2.95 | 4.55 | 64.8% |
| 31 | 0.277 | 1.137 | 24.4% | 3.18 | 5.12 | 62.1% | | | |
| 32 | 0.459 | 0.789 | 58.2% | 2.25 | 2.89 | 77.8% | 0.66 | 2.27 | 29.3% |
| 33 | 0.459 | 0.789 | 58.2% | 2.31 | 2.52 | 91.5% | 0.85 | 2.45 | 34.6% |
| 34 | 0.505 | 0.835 | 60.5% | 1.80 | 1.93 | 93.4% | 0.95 | 2.55 | 37.1% |
| 35 | 0.503 | 0.833 | 60.4% | 2.28 | 2.64 | 86.3% | 0.97 | 2.58 | 37.8% |
| 36 | 0.232 | 0.562 | 41.3% | 1.74 | 1.87 | 93.2% | 0.53 | 2.14 | 25.0% |
| 37 | 0.234 | 0.694 | 33.7% | 1.13 | 1.94 | 58.2% | 0.57 | 2.17 | 26.2% |
| 38 | 0.235 | 0.565 | 41.6% | 0.88 | 1.37 | 64.2% | 0.56 | 2.17 | 26.0% |
| 39 | 0.000 | 0.247 | 0.0% | 2.70 | 3.02 | 89.4% | 0.00 | 1.60 | 0.0% |
| 40 | 0.000 | 0.244 | 0.0% | 2.67 | 3.18 | 83.9% | 0.00 | 1.60 | 0.0% |
| 41 | 0.000 | 0.775 | 0.0% | | | | | | |
| 42 | 0.004 | 0.334 | 1.2% | | | | | | |
| 43 | 0.349 | 0.679 | 51.4% | | | | | | |
| AVERAGE: | | | 35.3% | | | 45.9% | | | 19.9% |

TABLE 5-9

CRUDE OIL LOADING: API MODEL USING TVP NOMOGRAPH ADJUSTMENT(a)

| Test Number | (a) Location (Tanker/ Barge) | Tanker Dead Weight (Mtons) | TVP (psia) | (b) Adjusted TVP (psia) | Total Calculated Emissions (lb/Mgal) | Adj. TVP Total Calculated Emissions (lb/Mgal) | Measured Emissions (lb/1000gal) | (c) Total vs. Adjusted | (d) Adjusted vs. Measured |
|---|---|---|---|---|---|---|---|---|---|
| 1 | A(T) | 135 | 3.1 | 5.6 | 1.054 | 1.280 | 2.48 | -17.7% | -48.3% |
| 2 | A(T) | 165 | 6.5 | 9 | 1.402 | 1.646 | 5.09 | -14.8% | -67.7% |
| 3 | A(T) | 265 | 6.3 | 8.8 | 1.413 | 1.671 | 3.43 | -15.5% | -51.3% |
| 4 | A(T) | 90 | 6.6 | 9.1 | 1.391 | 1.626 | 4.31 | -14.5% | -62.3% |
| 5 | A(T) | 80 | 7.8 | 10.3 | 1.489 | 1.719 | 4.54 | -13.4% | -62.1% |
| 6 | A(T) | 165 | 7 | 9.5 | 1.417 | 1.648 | 3.88 | -14.0% | -57.5% |
| 7 | A(T) | 120 | 8.1 | 10.6 | 1.562 | 1.807 | 4.18 | -13.6% | -56.7% |
| 8 | A(T) | 90 | 3 | 5.5 | 1.059 | 1.303 | 1.70 | -18.7% | -23.2% |
| 9 | A(T) | 120 | 3.2 | 5.7 | 1.076 | 1.316 | 1.48 | -18.3% | -10.8% |
| 10 | A(T) | 80 | 4.6 | 7.1 | 1.199 | 1.432 | 4.19 | -16.2% | -65.8% |
| 11 | A(T) | 120 | 4.5 | 7 | 1.196 | 1.433 | 2.28 | -16.5% | -37.2% |
| 12 | A(T) | 165 | 6.5 | 9 | 1.330 | 1.542 | 3.26 | -13.7% | -52.7% |
| 13 | A(T) | 120 | 7.2 | 9.7 | 1.442 | 1.674 | 2.34 | -13.9% | -28.5% |
| 14 | A(T) | 135 | 6.3 | 8.8 | 1.345 | 1.571 | 2.48 | -14.4% | -36.8% |
| 15 | A(T) | 80 | 7.1 | 9.6 | 1.394 | 1.612 | 3.62 | -13.5% | -55.4% |
| 16 | A(T) | 120 | 7 | 9.5 | 1.409 | 1.637 | 2.49 | -13.9% | -34.3% |
| 17 | A(T) | 75 | 8 | 10.5 | 1.552 | 1.797 | 3.13 | -13.7% | -42.6% |
| 18 | A(T) | 80 | 7.5 | 10 | 1.469 | 1.701 | 3.52 | -13.7% | -51.7% |
| 19 | A(T) | 120 | 4.1 | 6.6 | 1.149 | 1.379 | 1.41 | -16.7% | -2.1% |
| 20 | A(T) | 80 | 5 | 7.5 | 1.226 | 1.453 | 3.43 | -15.6% | -57.7% |
| 21 | A(T) | 165 | 4.7 | 7.2 | 1.202 | 1.431 | 4.22 | -16.0% | -66.1% |
| 22 | A(T) | 80 | 5 | 7.5 | 1.233 | 1.463 | 2.31 | -15.7% | -36.8% |
| 23 | A(T) | 190 | 6 | 8.5 | 1.345 | 1.586 | 3.67 | -15.2% | -56.8% |
| 24 | A(T) | 165 | 6 | 8.5 | 1.324 | 1.554 | 5.50 | -14.8% | -71.7% |
| 25 | A(T) | 165 | 6.9 | 9.4 | 1.394 | 1.618 | 4.85 | -13.9% | -66.6% |
| 26 | L48(T) | 28 | 3.8 | 6.3 | 0.583 | 0.806 | 0.62 | -27.6% | 30.0% |
| 27 | L48(T) | 28 | 4.4 | 6.9 | 1.170 | 1.394 | 1.25 | -16.1% | 11.5% |
| 28 | L48(T) | 28 | 4.4 | 6.9 | 0.640 | 0.865 | 0.70 | -26.0% | 23.6% |
| 29 | L48(T) | 28 | 4 | 6.5 | 0.608 | 0.837 | 1.72 | -27.3% | -51.3% |
| 30 | L48(T) | 28 | 4 | 6.5 | 0.608 | 0.837 | 1.72 | -27.3% | -51.3% |
| 31 | L48(T) | 28 | 4 | 6.5 | 1.137 | 1.365 | 1.98 | -16.7% | -31.1% |
| 32 | L48(T) | 17 | 6 | 8.5 | 0.789 | 1.016 | 1.22 | -22.4% | -16.7% |
| 33 | L48(T) | 17 | 6 | 8.5 | 0.789 | 1.016 | 0.69 | -22.4% | 47.2% |
| 34 | L48(T) | 17 | 6.5 | 9 | 0.835 | 1.063 | 0.97 | -21.4% | 9.5% |
| 35 | L48(T) | 17 | 6.5 | 9 | 0.833 | 1.060 | 0.87 | -21.4% | 21.8% |

NOTES:

(a) A(T)=Alyeska test database(Tanker) L48(T)=Lower 48 states database(Tanker)

graph adjusted +2.5 psia.

(c) %-Difference = (Total - Adjusted)/Adjusted

(d) %-Difference = (Adjusted-Measured)/Measured

TABLE 5-9
CRUDE OIL LOADING: API MODEL USING TVP NOMOGRAPH ADJUSTMENT(a)

| Test Number | (a) Location (Tanker/ Barge) | Tanker Dead Weight (Mtons) | TVP (psia) | (b) Adjusted TVP (psia) | Total Calculated Emissions (lb/Mgal) | Adj. TVP Total Calculated Emissions (lb/Mgal) | Measured Emissions (lb/1000gal) | (c) Total vs. Adjusted | (d) Adjusted vs. Measured |
|---|---|---|---|---|---|---|---|---|---|
| 36 | L48(T) | 17 | 3.5 | 6 | 0.562 | 0.790 | 0.32 | -28.9% | 147.0% |
| 37 | L48(T) | 17 | 3.5 | 6 | 0.694 | 0.923 | 1.02 | -24.9% | -9.5% |
| 38 | L48(T) | 17 | 3.5 | 6 | 0.565 | 0.796 | 0.68 | -29.0% | 17.0% |
| 39 | L48(T) | 35 | 0 | 2.5 | 0.247 | 0.465 | 0.2 | -46.9% | 132.3% |
| 40 | L48(T) | 35 | 0 | 2.5 | 0.244 | 0.470 | 0.38 | -48.1% | 23.6% |
| 41 | L48(T) | 35 | 0 | 2.5 | 0.775 | 0.998 | 1.08 | -22.3% | -7.6% |
| 42 | L48(T) | | 1 | 3.5 | 0.334 | 0.560 | 0.60 | -40.3% | -6.7% |
| 43 | L48(T) | 30 | 4.8 | 7.3 | 0.679 | 0.906 | 0.98 | -25.0% | -7.6% |
| | | AVERAGES: | | | 1.05 | 1.28 | 2.34 | -20.3% | -21.4% |
| | | ABSOLUTE AVERAGE: | | | | | | 20.3% | 43.0% |

NOTES:

(a) A(T)=Alyeska test database(Tanker) L48(T)=Lower 48 states database(Tanker)
graph adjusted +2.5 psia.

(c) %-Difference = (Total - Adjusted)/Adjusted

(d) %-Difference = (Adjusted-Measured)/Measured

TABLE 5-10
GASOLINE LOADING DATA BASE(a)

| Test Number | Date | (b) Category | (c) Tanker/ Barge | Tanker Name | Tanker (DWT) | Test Location |
|---|---|---|---|---|---|---|
| 1 | Jan-14-75 | 1 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 2 | Jan-14-75 | 1 | TANKER | NR | NR | LOWER 48 STATES |
| 3 | Jan-14-75 | 1 | TANKER | NR | NR | LOWER 48 STATES |
| 4 | Jan-28-75 | 1 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 5 | Jan-28-75 | 1 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 6 | Jan-29-75 | 1 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 7 | Jan-29-75 | 1 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 8 | Jan-29-75 | 2 | TANKER | NR | NR | LOWER 48 STATES |
| 9 | Jan-29-75 | 2 | TANKER | NR | NR | LOWER 48 STATES |
| 10 | Dec-3-74 | 1 | BARGE | EXXON PORT EVERGLADES | <10,000 | LOWER 48 STATES |
| 11 | Dec-3-74 | 1 | BARGE | EXXON PORT EVERGLADES | <10,000 | LOWER 48 STATES |
| 12 | Jan-8-75 | 1 | BARGE | EXXON PORT EVERGLADES | <10,000 | LOWER 48 STATES |
| 13 | Jan-8-75 | 1 | BARGE | EXXON PORT EVERGLADES | <10,000 | LOWER 48 STATES |
| 14 | Jan-8-75 | 1 | BARGE | EXXON PORT EVERGLADES | <10,000 | LOWER 48 STATES |
| 15 | Jan-8-75 | 1 | BARGE | EXXON PORT EVERGLADES | <10,000 | LOWER 48 STATES |
| 16 | Aug-17-75 | 1 | TANKER | NR | NR | LOWER 48 STATES |
| 17 | Aug-17-75 | 1 | TANKER | NR | NR | LOWER 48 STATES |
| 18 | Jul-30-75 | 1 | TANKER | NR | NR | LOWER 48 STATES |
| 19 | Jul-30-75 | 1 | TANKER | EXXON GETTSYBURG | 39,029 | LOWER 48 STATES |
| 20 | Jul-30-75 | 1 | TANKER | EXXON GETTSYBURG | 39,029 | LOWER 48 STATES |
| 21 | Jul-30-75 | 1 | TANKER | EXXON GETTSYBURG | 39,029 | LOWER 48 STATES |
| 22 | Jul-30-75 | 1 | TANKER | EXXON GETTSYBURG | 39,029 | LOWER 48 STATES |
| 23 | Jul-30-75 | 1 | TANKER | EXXON GETTSYBURG | 39,029 | LOWER 48 STATES |
| 24 | Jul-30-75 | 1 | TANKER | NR | NR | LOWER 48 STATES |
| 25 | Aug-5-75 | 1 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 26 | Aug-10-75 | 1 | TANKER | EXXON SAN FRANCISCO | 75,149 | LOWER 48 STATES |
| 27 | Jul-27-75 | 1 | TANKER | EXXON SAN FRANCISCO | 75,149 | LOWER 48 STATES |
| 28 | Jul-28-75 | 1 | TANKER | EXXON SAN FRANCISCO | 75,149 | LOWER 48 STATES |
| 29 | Jul-28-75 | 1 | TANKER | EXXON SAN FRANCISCO | 75,149 | LOWER 48 STATES |
| 30 | Jul-28-75 | 1 | TANKER | EXXON SAN FRANCISCO | 75,149 | LOWER 48 STATES |
| 31 | Feb-13-75 | 3 | TANKER | NR | NR | LOWER 48 STATES |
| 32 | Mar-30-75 | 1 | TANKER | NR | NR | LOWER 48 STATES |
| 33 | Apr-2-75 | 1 | TANKER | NR | NR | LOWER 48 STATES |
| 34 | Dec-17-74 | 1 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 35 | Dec-27-74 | 1 | TANKER | NR | NR | LOWER 48 STATES |

NOTES:

(a) Data base was obtained from API Emission Factor Study and EPA 8-31 Marine Emission Study.

(b) Category 1 - Tanker: Volatile prior cargo, Compartment was uncleaned.
Category 2 - Tanker: Volatile prior cargo, Compartment was ballasted.
Category 3 - Tanker: Volatile prior cargo, Compartment was cleaned.
Category 4 - Tanker: Volatile prior cargo, Compartment was gas freed.
Category 5 - Barge: Volatile prior cargo, Compartment was uncleaned.
Category 6 - Barge: Volatile prior cargo, Compartment cleaned/gas freed.

(c) Dead weight tonage of tankers and barges are not known.

NR = Not Recorded

TABLE 5-10
GASOLINE LOADING DATA BASE(a)

| Test Number | Date | (b) Category | (c) Tanker/ Barge | Tanker Name | Tanker (DWT) | Test Location |
|---|---|---|---|---|---|---|
| 36 | Dec-30-74 | 1 | TANKER | NR | NR | LOWER 48 STATES |
| 37 | Apr-19-75 | 1 | TANKER | NR | NR | LOWER 48 STATES |
| 38 | Nov-12-74 | 2 | TANKER | EXXON BOSTON | 51,966 | LOWER 48 STATES |
| 39 | Nov-12-74 | 2 | TANKER | EXXON BOSTON | 51,966 | LOWER 48 STATES |
| 40 | Nov-15-74 | 2 | TANKER | NR | NR | LOWER 48 STATES |
| 41 | Jan-14-75 | 2 | TANKER | NR | NR | LOWER 48 STATES |
| 42 | Jan-8-75 | 2 | BARGE | EXXON PORT EVERGLADES | <10,000 | LOWER 48 STATES |
| 43 | Jan-8-75 | 2 | BARGE | EXXON PORT EVERGLADES | <10,000 | LOWER 48 STATES |
| 44 | Aug-17-75 | 2 | TANKER | EXXON GETTYSBURG | 39,029 | LOWER 48 STATES |
| 45 | Aug-5-75 | 2 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 46 | Sep-2-75 | 2 | BARGE | EXXON PORT EVERGLADES | <10,000 | LOWER 48 STATES |
| 47 | Apr-28-75 | 3 | TANKER | NR | NR | LOWER 48 STATES |
| 48 | Apr-28-75 | 3 | TANKER | NR | NR | LOWER 48 STATES |
| 49 | NR | 2 | TANKER | NR | NR | LOWER 48 STATES |
| 50 | NR | 2 | TANKER | NR | NR | LOWER 48 STATES |
| 51 | NR | 2 | TANKER | NR | NR | LOWER 48 STATES |
| 52 | Dec-15-74 | 3 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 53 | Jan-28-75 | 3 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 54 | Feb-13-75 | 3 | TANKER | NR | NR | LOWER 48 STATES |
| 55 | Oct-74 | 3 | TANKER | NR | NR | LOWER 48 STATES |
| 56 | Oct-74 | 3 | TANKER | NR | NR | LOWER 48 STATES |
| 57 | Oct-74 | 3 | TANKER | NR | NR | LOWER 48 STATES |
| 58 | Oct-74 | 3 | TANKER | NR | NR | LOWER 48 STATES |
| 59 | Nov-17-74 | 4 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 60 | Nov-20-74 | 4 | TANKER | EXXON JAMESTOWN | 39,028 | LOWER 48 STATES |
| 61 | Dec-15-74 | 4 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 62 | Dec-17-74 | 4 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 63 | Dec-17-74 | 1 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 64 | Jan-14-75 | 4 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 65 | Jan-14-75 | 4 | TANKER | NR | NR | LOWER 48 STATES |
| 66 | Jan-15-75 | 4 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 67 | Jan-16-75 | 4 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 68 | Jan-16-75 | 4 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 69 | Jan-16-75 | 4 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 70 | Jan-19-75 | 4 | TANKER | EXXON GETTYSBURG | 39,029 | LOWER 48 STATES |

NOTES:

(a) Data base was obtained from API Emission Factor Study and EPA 8-31 Marine Emission Study.

(b) Category 1 – Tanker: Volatile prior cargo, Compartment was uncleaned.
Category 2 – Tanker: Volatile prior cargo, Compartment was ballasted.
Category 3 – Tanker: Volatile prior cargo, Compartment was cleaned.
Category 4 – Tanker: Volatile prior cargo, Compartment was gas freed.
Category 5 – Barge: Volatile prior cargo, Compartment was uncleaned.
Category 6 – Barge: Volatile prior cargo, Compartment cleaned/gas freed.

(c) Dead weight tonage of tankers and barges are not known.

NR = Not Recorded

TABLE 5-10
GASOLINE LOADING DATA BASE(a)

| Test Number | Date | (b) Category | (c) Tanker/ Barge | Tanker Name | Tanker (DWT) | Test Location |
|---|---|---|---|---|---|---|
| 71 | Jan-19-75 | 4 | TANKER | EXXON GETTYSBURG | 39,029 | LOWER 48 STATES |
| 72 | Jan-19-75 | 4 | TANKER | EXXON GETTYSBURG | 39,029 | LOWER 48 STATES |
| 73 | Jan-29-75 | 4 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 74 | Aug-6-75 | 4 | TANKER | EXXON BOSTON | 51,966 | LOWER 48 STATES |
| 75 | Aug-6-75 | 4 | TANKER | EXXON BOSTON | 51,966 | LOWER 48 STATES |
| 76 | Aug-6-75 | 4 | TANKER | EXXON BOSTON | 51,966 | LOWER 48 STATES |
| 77 | Aug-6-75 | 4 | TANKER | EXXON BOSTON | 51,966 | LOWER 48 STATES |
| 78 | Aug-2-75 | 4 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 79 | Aug-2-75 | 4 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 80 | Aug-16-75 | 4 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 81 | Aug-16-75 | 4 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 82 | Aug-16-75 | 4 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 83 | Aug-16-75 | 4 | TANKER | EXXON BATON ROUGE | 75,649 | LOWER 48 STATES |
| 84 | Aug-17-75 | 4 | TANKER | EXXON GETTYSBURG | 39,029 | LOWER 48 STATES |
| 85 | Aug-5-75 | 4 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 86 | Dec-16-74 | 4 | TANKER | EXXON NEW ORLEANS | 67,847 | LOWER 48 STATES |
| 87 | Jan-19-75 | 4 | TANKER | EXXON GETTYSBURG | 39,029 | LOWER 48 STATES |
| 88 | Sep-2-75 | 4 | BARGE | EXXON PORT EVERGLADES | <10,000 | LOWER 48 STATES |
| 89 | Nov-13-74 | 4 | TANKER | NR | NR | LOWER 48 STATES |
| 90 | Feb-13-75 | 4 | TANKER | NR | NR | LOWER 48 STATES |
| 91 | NR (M4) | 4 | TANKER | NR | NR | LOWER 48 STATES |
| 92 | NR (M6) | 4 | TANKER | NR | NR | LOWER 48 STATES |
| 93 | NR (M7) | 4 | TANKER | NR | NR | LOWER 48 STATES |
| 94 | Nov-27-74 | 1 | TANKER | NMS 40 | NR | LOWER 48 STATES |
| 95 | Nov-8-74 | 5 | BARGE | GDM 40 | NR | LOWER 48 STATES |
| 96 | Nov-22-74 | 5 | BARGE | NMS 40 | NR | LOWER 48 STATES |
| 97 | Nov-22-74 | 5 | BARGE | NMS 40 | NR | LOWER 48 STATES |
| 98 | Nov-22-74 | 5 | BARGE | NMS 40 | NR | LOWER 48 STATES |
| 99 | Dec-4-74 | 5 | BARGE | EXXON BARGE 119 | NR | LOWER 48 STATES |
| 100 | Dec-4-74 | 5 | BARGE | EXXON BARGE 119 | NR | LOWER 48 STATES |
| 101 | Dec-4-74 | 5 | BARGE | EXXON BARGE 119 | NR | LOWER 48 STATES |
| 102 | Dec-4-74 | 5 | BARGE | EXXON BARGE 119 | NR | LOWER 48 STATES |
| 103 | Aug-13-75 | 5 | BARGE | PATCO 200 | NR | LOWER 48 STATES |
| 104 | Aug-13-75 | 5 | BARGE | PATCO 200 | NR | LOWER 48 STATES |
| 105 | Aug-13-75 | 5 | BARGE | PATCO 200 | NR | LOWER 48 STATES |

NOTES:

(a) Data base was obtained from API Emission Factor Study and EPA 8-31 Marine Emission Study.

(b) Category 1 – Tanker: Volatile prior cargo, Compartment was uncleaned.
Category 2 – Tanker: Volatile prior cargo, Compartment was ballasted.
Category 3 – Tanker: Volatile prior cargo, Compartment was cleaned.
Category 4 – Tanker: Volatile prior cargo, Compartment was gas freed.
Category 5 – Barge: Volatile prior cargo, Compartment was uncleaned.
Category 6 – Barge: Volatile prior cargo, Compartment cleaned/gas freed.

(c) Dead weight tonage of tankers and barges are not known.

NR = Not Recorded

TABLE 5-10
GASOLINE LOADING DATA BASE(a)

| Test Number | Date | (b) Category | (c) Tanker/ Barge | Tanker Name | Tanker (DWT) | Test Location |
|---|---|---|---|---|---|---|
| 106 | Aug-13-75 | 5 | BARGE | PATCO 200 | NR | LOWER 48 STATES |
| 107 | Aug-13-75 | 5 | BARGE | PATCO 200 | NR | LOWER 48 STATES |
| 108 | Aug-13-75 | 5 | BARGE | PATCO 200 | NR | LOWER 48 STATES |
| 109 | NR (M9) | 5 | BARGE | NR | NR | LOWER 48 STATES |
| 110 | NR (M10) | 5 | BARGE | NR | NR | LOWER 48 STATES |
| 111 | NR (M8) | 6 | BARGE | NR | NR | LOWER 48 STATES |
| 112 | Jul-21-78 | 6 | BARGE | NR | NR | LOWER 48 STATES |
| 113 | Jul-21-78 | 6 | BARGE | NR | NR | LOWER 48 STATES |
| 114 | Jul-21-78 | 6 | BARGE | NR | NR | LOWER 48 STATES |
| 115 | May-15-78(2S) | 6 | BARGE | NR | NR | LOWER 48 STATES |
| 116 | May-15-78(4P) | 6 | BARGE | NR | NR | LOWER 48 STATES |
| 117 | May-15-78(4S) | 6 | BARGE | NR | NR | LOWER 48 STATES |
| 118 | NR | 6 | BARGE | NR | NR | LOWER 48 STATES |
| 119 | NR | 6 | BARGE | NR | NR | LOWER 48 STATES |
| 120 | NR | 6 | BARGE | NR | NR | LOWER 48 STATES |
| 121 | NR | 5 | BARGE | NR | NR | LOWER 48 STATES |
| 122 | NR | 5 | BARGE | NR | NR | LOWER 48 STATES |
| 123 | NR | 5 | BARGE | NR | NR | LOWER 48 STATES |

NOTES:

(a) Data base was obtained from API Emission Factor Study and EPA 8-31 Marine Emission Study.

(b) Category 1 - Tanker: Volatile prior cargo, Compartment was uncleaned.
Category 2 - Tanker: Volatile prior cargo, Compartment was ballasted.
Category 3 - Tanker: Volatile prior cargo, Compartment was cleaned.
Category 4 - Tanker: Volatile prior cargo, Compartment was gas freed.
Category 5 - Barge: Volatile prior cargo, Compartment was uncleaned.
Category 6 - Barge: Volatile prior cargo, Compartment cleaned/gas freed.

(c) Dead weight tonage of tankers and barges are not known.

NR = Not Recorded

TABLE 5-11
GASOLINE LOADING EMISSIONS:
MEASURED DATA vs. API PREDICTION

| Test Number | (a) Tanker/ Compartment Category | Tanker/ Barge | Tanker (DWT) | (b) Test Location | API Emission Factor(Et) (lb/Mgal) | API Measured Emissions (lb/Mgal) | (c) Percent Difference (%) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | TANKER | 67,847 | L48 | 2.6 | 1.06 | 144.6% |
| 2 | 1 | TANKER | NR | L48 | 2.6 | 1.64 | 58.4% |
| 3 | 1 | TANKER | NR | L48 | 2.6 | 0.59 | 343.7% |
| 4 | 1 | TANKER | 75,649 | L48 | 2.6 | 1.60 | 62.6% |
| 5 | 1 | TANKER | 75,649 | L48 | 2.6 | 1.29 | 101.4% |
| 6 | 1 | TANKER | 67,847 | L48 | 2.6 | 2.76 | -5.9% |
| 7 | 1 | TANKER | 67,847 | L48 | 2.6 | 1.43 | 81.3% |
| 8 | 2 | TANKER | NR | L48 | 1.7 | 4.20 | -59.5% |
| 9 | 2 | TANKER | NR | L48 | 1.7 | 4.10 | -58.6% |
| 10 | 1 | BARGE | <10,000 | L48 | 2.6 | 4.31 | -39.7% |
| 11 | 1 | BARGE | <10,000 | L48 | 2.6 | 3.66 | -28.9% |
| 12 | 1 | BARGE | <10,000 | L48 | 2.6 | 3.30 | -21.2% |
| 13 | 1 | BARGE | <10,000 | L48 | 2.6 | 1.80 | 44.8% |
| 14 | 1 | BARGE | <10,000 | L48 | 2.6 | 3.32 | -21.6% |
| 15 | 1 | BARGE | <10,000 | L48 | 2.6 | 3.24 | -19.7% |
| 16 | 1 | TANKER | NR | L48 | 2.6 | 2.26 | 14.9% |
| 17 | 1 | TANKER | NR | L48 | 2.6 | 2.06 | 26.5% |
| 18 | 1 | TANKER | NR | L48 | 2.6 | 4.22 | -38.3% |
| 19 | 1 | TANKER | 39,029 | L48 | 2.6 | 2.67 | -2.7% |
| 20 | 1 | TANKER | 39,029 | L48 | 2.6 | 3.52 | -26.1% |
| 21 | 1 | TANKER | 39,029 | L48 | 2.6 | 2.92 | -10.9% |
| 22 | 1 | TANKER | 39,029 | L48 | 2.6 | 3.25 | -20.0% |
| 23 | 1 | TANKER | 39,029 | L48 | 2.6 | 0.29 | 787.7% |
| 24 | 1 | TANKER | NR | L48 | 2.6 | 2.15 | 21.0% |
| 25 | 1 | TANKER | 67,847 | L48 | 2.6 | 1.97 | 31.8% |
| 26 | 1 | TANKER | 75,149 | L48 | 2.6 | 1.74 | 49.4% |
| 27 | 1 | TANKER | 75,149 | L48 | 2.6 | 3.633 | -28.4% |
| 28 | 1 | TANKER | 75,149 | L48 | 2.6 | 2.568 | 1.2% |
| 29 | 1 | TANKER | 75,149 | L48 | 2.6 | 3.25 | -20.0% |
| 30 | 1 | TANKER | 75,149 | L48 | 2.6 | 3.565 | -27.1% |
| 31 | 3 | TANKER | NR | L48 | 1.5 | 1.6 | -6.3% |
| 32 | 1 | TANKER | NR | L48 | 2.6 | 2.68 | -3.0% |
| 33 | 1 | TANKER | NR | L48 | 2.6 | 1.42 | 83.1% |
| 34 | 1 | TANKER | 75,649 | L48 | 2.6 | 2.52 | 3.2% |
| 35 | 1 | TANKER | NR | L48 | 2.6 | 2.65 | -1.9% |

NOTES:

(a) Category 1 – Tanker: Volatile prior cargo, Compartment was uncleaned.
Category 2 – Tanker: Volatile prior cargo, Compartment was ballasted.
Category 3 – Tanker: Volatile prior cargo, Compartment was cleaned.
Category 4 – Tanker: Volatile prior cargo, Compartment was gas freed.
Category 5 – Barge: Volatile prior cargo, Compartment was uncleaned.
Category 6 – Barge: Volatile prior cargo, Compartment cleaned/gas freed.

(b) L48=Lower 48 state database.

(c) Percent Difference = (Calculated–Measured)/Measured * 100%

NR = Not Recorded

TABLE 5-11
GASOLINE LOADING EMISSIONS:
MEASURED DATA vs. API PREDICTION

| Test Number | (a) Tanker/ Compartment Category | Tanker/ Barge | Tanker (DWT) | (b) Test Location | API Emission Factor(Et) (lb/Mgal) | API Measured Emissions (lb/Mgal) | (c) Percent Difference (%) |
|---|---|---|---|---|---|---|---|
| 36 | 1 | TANKER | NR | L48 | 2.6 | 2.93 | -11.3% |
| 37 | 1 | TANKER | NR | L48 | 2.6 | 3.57 | -27.2% |
| 38 | 2 | TANKER | 51,966 | L48 | 1.7 | 1.823 | -6.7% |
| 39 | 2 | TANKER | 51,966 | L48 | 1.7 | 1.858 | -8.5% |
| 40 | 2 | TANKER | NR | L48 | 1.7 | 2.281 | -25.5% |
| 41 | 2 | TANKER | NR | L48 | 1.7 | 2.503 | -32.1% |
| 42 | 2 | BARGE | <10,000 | L48 | 1.7 | 0.683 | 148.9% |
| 43 | 2 | BARGE | <10,000 | L48 | 1.7 | 1.447 | 17.5% |
| 44 | 2 | TANKER | 39,029 | L48 | 1.7 | 2.664 | -36.2% |
| 45 | 2 | TANKER | 67,847 | L48 | 1.7 | 1.151 | 47.7% |
| 46 | 2 | BARGE | <10,000 | L48 | 1.7 | 4.491 | -62.1% |
| 47 | 3 | TANKER | NR | L48 | 1.5 | 0.7 | 114.3% |
| 48 | 3 | TANKER | NR | L48 | 1.5 | 0.44 | 240.9% |
| 49 | 2 | TANKER | NR | L48 | 1.7 | 1.31 | 29.8% |
| 50 | 2 | TANKER | NR | L48 | 1.7 | 1.13 | 50.4% |
| 51 | 2 | TANKER | NR | L48 | 1.7 | 0.97 | 75.3% |
| 52 | 3 | TANKER | 67,847 | L48 | 1.5 | 0.921 | 62.9% |
| 53 | 3 | TANKER | 75,649 | L48 | 1.5 | 0.689 | 117.7% |
| 54 | 3 | TANKER | NR | L48 | 1.5 | 1.3 | 15.4% |
| 55 | 3 | TANKER | NR | L48 | 1.5 | 1.6 | -6.3% |
| 56 | 3 | TANKER | NR | L48 | 1.5 | 1.79 | -16.2% |
| 57 | 3 | TANKER | NR | L48 | 1.5 | 1.8 | -16.7% |
| 58 | 3 | TANKER | NR | L48 | 1.5 | 2 | -25.0% |
| 59 | 4 | TANKER | 67,847 | L48 | 0.7 | -0.139 | -603.6% |
| 60 | 4 | TANKER | 39,028 | L48 | 0.7 | 0.471 | 48.6% |
| 61 | 4 | TANKER | 67,847 | L48 | 0.7 | 0.304 | 130.3% |
| 62 | 4 | TANKER | 75,649 | L48 | 0.7 | 0.569 | 23.0% |
| 63 | 1 | TANKER | 75,649 | L48 | 2.6 | 0.377 | 589.7% |
| 64 | 4 | TANKER | 67,847 | L48 | 0.7 | 0.658 | 6.4% |
| 65 | 4 | TANKER | NR | L48 | 0.7 | 0.226 | 209.7% |
| 66 | 4 | TANKER | 75,649 | L48 | 0.7 | 0.709 | -1.3% |
| 67 | 4 | TANKER | 75,649 | L48 | 0.7 | 0.497 | 40.8% |
| 68 | 4 | TANKER | 75,649 | L48 | 0.7 | 0.879 | -20.4% |
| 69 | 4 | TANKER | 75,649 | L48 | 0.7 | 0.594 | 17.8% |
| 70 | 4 | TANKER | 39,029 | L48 | 0.7 | 0.517 | 35.4% |

NOTES:

(a) Category 1 – Tanker: Volatile prior cargo, Compartment was uncleaned.
Category 2 – Tanker: Volatile prior cargo, Compartment was ballasted.
Category 3 – Tanker: Volatile prior cargo, Compartment was cleaned.
Category 4 – Tanker: Volatile prior cargo, Compartment was gas freed.
Category 5 – Barge: Volatile prior cargo, Compartment was uncleaned.
Category 6 – Barge: Volatile prior cargo, Compartment cleaned/gas freed.

(b) L48=Lower 48 state database.

(c) Percent Difference = (Calculated–Measured)/Measured * 100%

NR = Not Recorded

TABLE 5-11
GASOLINE LOADING EMISSIONS:
MEASURED DATA vs. API PREDICTION

| Test Number | (a) Tanker/ Compartment Category | Tanker/ Barge | Tanker (DWT) | (b) Test Location | API Emission Factor(Et) (lb/Mgal) | API Measured Emissions (lb/Mgal) | (c) Percent Difference (%) |
|---|---|---|---|---|---|---|---|
| 71 | 4 | TANKER | 39,029 | L48 | 0.7 | 0.399 | 75.4% |
| 72 | 4 | TANKER | 39,029 | L48 | 0.7 | 0.327 | 114.1% |
| 73 | 4 | TANKER | 67,847 | L48 | 0.7 | 0.594 | 17.8% |
| 74 | 4 | TANKER | 51,966 | L48 | 0.7 | 0.474 | 47.7% |
| 75 | 4 | TANKER | 51,966 | L48 | 0.7 | 0.546 | 28.2% |
| 76 | 4 | TANKER | 51,966 | L48 | 0.7 | 0.693 | 1.0% |
| 77 | 4 | TANKER | 51,966 | L48 | 0.7 | 0.764 | -8.4% |
| 78 | 4 | TANKER | 75,649 | L48 | 0.7 | 1.167 | -40.0% |
| 79 | 4 | TANKER | 75,649 | L48 | 0.7 | 1.078 | -35.1% |
| 80 | 4 | TANKER | 75,649 | L48 | 0.7 | 0.377 | 85.7% |
| 81 | 4 | TANKER | 75,649 | L48 | 0.7 | 0.443 | 58.0% |
| 82 | 4 | TANKER | 75,649 | L48 | 0.7 | 0.998 | -29.9% |
| 83 | 4 | TANKER | 75,649 | L48 | 0.7 | 0.769 | -9.0% |
| 84 | 4 | TANKER | 39,029 | L48 | 0.7 | 0.376 | 86.2% |
| 85 | 4 | TANKER | 67,847 | L48 | 0.7 | 0.327 | 114.1% |
| 86 | 4 | TANKER | 67,847 | L48 | 0.7 | 0.446 | 57.0% |
| 87 | 4 | TANKER | 39,029 | L48 | 0.7 | 0.539 | 29.9% |
| 88 | 4 | BARGE | <10,000 | L48 | 0.7 | 1.323 | -47.1% |
| 89 | 4 | TANKER | NR | L48 | 0.7 | 0.42 | 66.7% |
| 90 | 4 | TANKER | NR | L48 | 0.7 | 1.14 | -38.6% |
| 91 | 4 | TANKER | NR | L48 | 0.7 | 1.71 | -59.1% |
| 92 | 4 | TANKER | NR | L48 | 0.7 | 1.48 | -52.7% |
| 93 | 4 | TANKER | NR | L48 | 0.7 | 2.08 | -66.3% |
| 94 | 1 | TANKER | NR | L48 | 2.6 | 0.54 | 381.5% |
| 95 | 5 | BARGE | NR | L48 | 3.9 | 3.14 | 24.2% |
| 96 | 5 | BARGE | NR | L48 | 3.9 | 4.092 | -4.7% |
| 97 | 5 | BARGE | NR | L48 | 3.9 | 4.993 | -21.9% |
| 98 | 5 | BARGE | NR | L48 | 3.9 | 4.496 | -13.3% |
| 99 | 5 | BARGE | NR | L48 | 3.9 | 2.626 | 48.5% |
| 100 | 5 | BARGE | NR | L48 | 3.9 | 2.693 | 44.8% |
| 101 | 5 | BARGE | NR | L48 | 3.9 | 3.659 | 6.6% |
| 102 | 5 | BARGE | NR | L48 | 3.9 | 3.526 | 10.6% |
| 103 | 5 | BARGE | NR | L48 | 3.9 | 3.984 | -2.1% |
| 104 | 5 | BARGE | NR | L48 | 3.9 | 4.189 | -6.9% |
| 105 | 5 | BARGE | NR | L48 | 3.9 | 4.505 | -13.4% |

NOTES:

(a) Category 1 - Tanker: Volatile prior cargo, Compartment was uncleaned.
Category 2 - Tanker: Volatile prior cargo, Compartment was ballasted.
Category 3 - Tanker: Volatile prior cargo, Compartment was cleaned.
Category 4 - Tanker: Volatile prior cargo, Compartment was gas freed.
Category 5 - Barge: Volatile prior cargo, Compartment was uncleaned.
Category 6 - Barge: Volatile prior cargo, Compartment cleaned/gas freed.

(b) L48=Lower 48 state database.

(c) Percent Difference = (Calculated-Measured)/Measured * 100%

NR = Not Recorded

TABLE 5-11
GASOLINE LOADING EMISSIONS:
MEASURED DATA vs. API PREDICTION

| Test Number | (a) Tanker/ Compartment Category | Tanker/ Barge | Tanker (DWT) | (b) Test Location | API Emission Factor(Et) (lb/Mgal) | API Measured Emissions (lb/Mgal) | (c) Percent Difference (%) |
|---|---|---|---|---|---|---|---|
| 106 | 5 | BARGE | NR | L48 | 3.9 | 5.575 | -30.0% |
| 107 | 5 | BARGE | NR | L48 | 3.9 | 4.998 | -22.0% |
| 108 | 5 | BARGE | NR | L48 | 3.9 | 4.498 | -13.3% |
| 109 | 5 | BARGE | NR | L48 | 3.9 | 3.06 | 27.5% |
| 110 | 5 | BARGE | NR | L48 | 3.9 | 2.31 | 68.8% |
| 111 | 6 | BARGE | NR | L48 | 2 | 1.48 | 35.1% |
| 112 | 6 | BARGE | NR | L48 | 2 | 2.3 | -13.0% |
| 113 | 6 | BARGE | NR | L48 | 2 | 2.2 | -9.1% |
| 114 | 6 | BARGE | NR | L48 | 2 | 2.1 | -4.8% |
| 115 | 6 | BARGE | NR | L48 | 2 | 9.65 | -79.3% |
| 116 | 6 | BARGE | NR | L48 | 2 | 2.76 | -27.5% |
| 117 | 6 | BARGE | NR | L48 | 2 | 3 | -33.3% |
| 118 | 6 | BARGE | NR | L48 | 2 | 9.65 | -79.3% |
| 119 | 6 | BARGE | NR | L48 | 2 | 2.75 | -27.3% |
| 120 | 6 | BARGE | NR | L48 | 2 | 2.99 | -33.2% |
| 121 | 5 | BARGE | NR | L48 | 3.9 | 2.29 | 70.4% |
| 122 | 5 | BARGE | NR | L48 | 3.9 | 2.18 | 79.0% |
| 123 | 5 | BARGE | NR | L48 | 3.9 | 2.09 | 86.5% |
| | | | | | AVERAGE | | 27.5% |
| | | | | | ABSOLUTE AVERAGE | | 62.6% |

NOTES:

(a) Category 1 - Tanker: Volatile prior cargo, Compartment was uncleaned.
Category 2 - Tanker: Volatile prior cargo, Compartment was ballasted.
Category 3 - Tanker: Volatile prior cargo, Compartment was cleaned.
Category 4 - Tanker: Volatile prior cargo, Compartment was gas freed.
Category 5 - Barge: Volatile prior cargo, Compartment was uncleaned.
Category 6 - Barge: Volatile prior cargo, Compartment cleaned/gas freed.

(b) L48=Lower 48 state database.

(c) Percent Difference = (Calculated-Measured)/Measured * 100%

NR = Not Recorded

TABLE 5-12

GASOLINE LOADING EMISSIONS: MEASURED DATA vs. EXXON MODEL PREDICTION

| (a) Test Number | TVP (psia) | Vessel Type | Surface Area (ft2) | Volume Loaded (Bbls) | Volume Loaded (cu ft.) | Final Ullage (ft) | Ullage Correction (ft3/ft2-psia) | Cu. Ft. HC Calculated | Ton HC Calculated | Ton HC Measured | (b) % Difference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 118 | 9 | BARGE | 917 | 1737 | 9753 | 1.29 | 0.02 | 3050 | 0.23 | 0.35 | -54.0 |
| 119 | 9 | BARGE | 916 | 1714 | 9624 | 1.46 | 0.02 | 3044 | 0.23 | 0.099 | 56.6 |
| 120 | 9 | BARGE | 916 | 1718 | 9647 | 1.44 | 0.02 | 3044 | 0.23 | 0.108 | 52.7 |
| 121 | 7.1 | BARGE | 1161 | 2392 | 13431 | 0.58 | 0.01 | 3960 | 0.30 | 0.12 | 61.2 |
| 122 | 7.1 | BARGE | 1157 | 2404 | 13498 | 0.44 | 0.01 | 3955 | 0.30 | 0.11 | 62.9 |
| 123 | 7.1 | BARGE | 1160 | 2437 | 13684 | 0.52 | 0.01 | 3977 | 0.30 | 0.107 | 64.1 |
| | | | | | | | | | AVERAGE: | | 40.6 |
| | | | | | | | | | ABSOLUTE AVERAGE | | 58.6 |

NOTES:

(a) Tests 1-117 (as indicated in Table 4-8) did not contain the necessary input parameters to calculate gasoline loading emissions using the Exxon model.

(b) %-Difference = (Calculated - Measured)/Measured * 100%

TABLE 5-13
GASOLINE LOADING EMISSIONS:
MEASURED DATA vs. API PREDICTION

| (a) Test Number | Vessel Type | API Calculated Emission (lb/Mgal) | EXXON Calculated Emission (lb/Mgal) | (b) % Difference |
|---|---|---|---|---|
| 118 | BARGE | 2 | 6.27 | -68.1 |
| 119 | BARGE | 2 | 6.34 | -68.4 |
| 120 | BARGE | 2 | 6.32 | -68.4 |
| 121 | BARGE | 3.9 | 5.91 | -34.0 |
| 122 | BARGE | 3.9 | 5.87 | -33.6 |
| 123 | BARGE | 3.9 | 5.82 | -33.0 |

NOTES:

(a) Tests 1-117 (as indicated in Table 4-8) did not contain the necessary input parameters to calculate gasoline loading emissions using the Exxon model.

(b) % Difference = (API-EXXON)/EXXON * 100%

TABLE 5-14
CRUDE OIL BALLASTING DATABASE DESCRIPTION

| Test Number | Date | Tanker MDWT | Tanker Name | Reference Number |
|---|---|---|---|---|
| 1 | Jan-27-78 | NR | NR | A-1-1 |
| 2 | Jan-27-78 | NR | NR | A-1-2 |
| 3 | Jan-27-78 | NR | NR | A-1-3 |
| 4 | May-23-78 | NR | NR | A-2-4(1C) |
| 5 | May-23-78 | NR | NR | A-2-5(3C) |
| 6 | May-23-78 | NR | NR | A-2-6(9C) |
| 7 | May-2-78 | NR | NR | A-3-7 |
| 8 | May-2-78 | NR | NR | A-3-8 |
| 9 | May-2-78 | NR | NR | A-3-9 |
| 10 | May-2-78 | NR | NR | A-3-10 |
| 11 | Apr-78 | NR | NR | A-4-11 |
| 12 | Apr-78 | NR | NR | A-4-12 |
| 13 | Apr-78 | NR | NR | A-4-13 |
| 14 | Jul-1-78 | 76 | Esso Castellon | A-5-14(2P) |
| 15 | Jul-1-78 | 76 | Esso Castellon | A-5-15(2S) |
| 16 | Jul-1-78 | 76 | Esso Castellon | A-5-16(4C) |
| 17 | Dec-3-77 | NR | M/T SANTA MARINA | A-6-17(4P) |
| 18 | Dec-3-77 | NR | M/T SANTA MARINA | A-6-18(4S) |
| 19 | Feb-23-78 | 100 | Panstar | A-7-19(1P) |
| 20 | Feb-23-78 | 100 | Panstar | A-7-20(1S) |
| 21 | May-26-78 | 53.3 | Arco Heritage | A-8-21(8P) |
| 22 | May-26-78 | 53.3 | Arco Heritage | A-8-22(9C) |
| 23 | May-26-78 | 53.3 | Arco Heritage | A-8-23(9P) |
| 24 | Feb-5-78 | 73 | Amoco Brisbane | A-9-24(1P) |
| 25 | Feb-5-78 | 73 | Amoco Brisbane | A-9-25(1S) |
| 26 | Feb-5-78 | 73 | Amoco Brisbane | A-9-26(4P) |
| 27 | Jul-20-78 | 78 | Amoco Yorktown | A-10-30(1P) |
| 28 | Jul-20-78 | 78 | Amoco Yorktown | A-10-31(1S) |
| 29 | Jul-20-78 | 78 | Amoco Yorktown | A-10-32(3P) |
| 30 | Nov-6-77 | NR | BURMA SPAR | A-11-36(2P) |
| 31 | Nov-6-77 | NR | BURMA SPAR | A-11-37(3C) |
| 32 | Nov-6-77 | NR | BURMA SPAR | A-11-38(4P) |
| 33 | Feb-14-78 | 70 | Esso Philippines | A-12-39(1P) |
| 34 | Feb-14-78 | 70 | Esso Philippines | A-12-40(1S) |
| 35 | Feb-14-78 | 70 | Esso Philippines | A-12-41(4F) |
| 36 | Apr-30-78 | NR | M/T SINGAPURA KEDUA | A-13-42(2P) |
| 37 | Apr-30-78 | NR | M/T SINGAPURA KEDUA | A-13-43(2S) |
| 38 | Apr-30-78 | NR | M/T SINGAPURA KEDUA | A-13-44(4P) |
| 39 | Jun-4-78 | 66.5 | Chevron JEGosline | A-14-45(1P) |
| 40 | Jun-4-78 | 66.5 | Chevron JEGosline | A-14-46(1S) |

Note:
(a) Data base was obtained from API Emission Factor Study

TABLE 5-14
CRUDE OIL BALLASTING DATABASE DESCRIPTION

| Test Number | Date | Tanker MDWT | Tanker Name | Reference Number |
|---|---|---|---|---|
| 41 | Oct-31-77 | 121 | Mobil Arctic | A-15-47(1P) |
| 42 | Oct-31-77 | 121 | Mobil Arctic | A-15-48(1S) |
| 43 | Oct-31-77 | 121 | Mobil Arctic | A-15-49(4C) |
| 44 | Jan-25-78 | 120 | Arco Anchorage | A-16-50(2S) |
| 45 | Jan-25-78 | 120 | Arco Anchorage | A-16-51(2P) |
| 46 | Apr-26-78 | 120.6 | Arco Juneau | A-17-52(2C) |
| 47 | May-24-78 | 49 | Exxon Baltimore | A-18-53(6P) |
| 48 | May-24-78 | 49 | Exxon Baltimore | A-18-54(6S) |
| 49 | May-24-78 | 49 | Exxon Baltimore | A-18-55(8S) |
| 50 | Jul-26-78 | 42.36 | Texaco Iowa | A-19-56(1C) |
| 51 | Jul-26-78 | 64.635 | Texaco Venezuela | A-19-57(3C) |
| 52 | Jul-26-78 | 64.635 | Texaco Venezuela | A-19-58(4C) |
| 53 | Jan-24-78 | 111 | Yorkshire | A-20-59(4P) |
| 54 | Jan-24-78 | 111 | Yorkshire | A-20-60(4S) |
| 55 | Mar-11-78 | 85 | Atomic | A-21(1C) |
| 56 | Mar-11-78 | 85 | Atomic | A-21(1C) |
| 57 | Mar-11-78 | 85 | Atomic | A-21(1C) |
| 58 | Mar-2-78 | 49.88 | Texaco Utah | UTAH-A(7C) |
| 59 | Mar-2-78 | 49.88 | Texaco Utah | UTAH-A(9C) |
| 60 | Mar-21-78 | 49.88 | Texaco Utah | UTAH-B(7C) |
| 61 | Mar-21-78 | 49.88 | Texaco Utah | UTAH-B(9C) |

Note:
(a) Data base was obtained from API Emission Factor Study

TABLE 5-15

CRUDE OIL BALLASTING EMISSIONS: MEASURED DATA vs. API MODEL PREDICTION

| Test Number | Date | Tanker MDWT | Tanker Name | RVP (psi) | Temp (F) | TVP (psi) | Arrival Ullage (ft) | Calculated Emission Factor | Measured Emission Factor | (a) % Difference |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Jan-27-78 | NR | NR | 3.6 | 60 | 1.8 | 2.4 | 0.71 | 0.39 | 82.9% |
| 2 | Jan-27-78 | NR | NR | 3.6 | 60 | 1.8 | 2.4 | 0.71 | 0.54 | 32.1% |
| 3 | Jan-27-78 | NR | NR | 3.6 | 60 | 1.8 | 5.8 | 0.77 | 0.56 | 38.3% |
| 4 | May-23-78 | NR | NR | 4.2 | 82 | 3.4 | 1.5 | 1.04 | 0.53 | 96.4% |
| 5 | May-23-78 | NR | NR | 4.2 | 82 | 3.4 | 1.5 | 1.04 | 0.59 | 76.4% |
| 6 | May-23-78 | NR | NR | 4.2 | 82 | 3.4 | 1.5 | 1.04 | 0.46 | 126.3% |
| 7 | May-2-78 | NR | NR | 4.8 | 62 | 2.7 | 1.5 | 0.89 | 1.29 | -31.0% |
| 8 | May-2-78 | NR | NR | 4.8 | 62 | 2.7 | 1.4 | 0.89 | 1.35 | -34.2% |
| 9 | May-2-78 | NR | NR | 4.6 | 66 | 2.8 | 1.35 | 0.91 | 1.18 | -23.1% |
| 10 | May-2-78 | NR | NR | 4.6 | 66 | 2.8 | 1.35 | 0.91 | 0.86 | 5.6% |
| 11 | Apr-78 | NR | NR | 8.5 | 65 | 6.3 | 10.4 | 2.23 | 1.18 | 88.6% |
| 12 | Apr-78 | NR | NR | 8.5 | 65 | 6.3 | 44.5 | 4.37 | 3.85 | 13.6% |
| 13 | Apr-78 | NR | NR | 8.5 | 65 | 6.3 | 1.4 | 1.66 | 0.96 | 72.7% |
| 14 | Jul-1-78 | 76 | Esso Castellon | 6.9 | 60 | 4.2 | 31.4 | 2.47 | 2.2 | 12.2% |
| 15 | Jul-1-78 | 76 | Esso Castellon | 6.9 | 60 | 4.2 | 34.8 | 2.61 | 3 | -12.9% |
| 16 | Jul-1-78 | 76 | Esso Castellon | 6.9 | 60 | 4.2 | 1.5 | 1.21 | 1.3 | -6.7% |
| 17 | Dec-3-77 | NR | M/T SANTA MARIN | 8.6 | 78 | 7.8 | 20.3 | 3.45 | 3.87 | -10.8% |
| 18 | Dec-3-77 | NR | M/T SANTA MARIN | 8.6 | 78 | 7.8 | 20 | 3.43 | 1.78 | 92.7% |
| 19 | Feb-23-78 | 100 | Panstar | 4.1 | 104 | 4.9 | 30 | 2.76 | 3.64 | -24.2% |

Note:

(a) %-Difference = (Calculated - Measured)/Measured * 100

TABLE 5-15

CRUDE OIL BALLASTING EMISSIONS: MEASURED DATA vs. API MODEL PREDICTION

| Test Number | Date | Tanker MDWT | Tanker Name | RVP (psi) | Temp (F) | TVP (psi) | Arrival Ullage (ft) | Calculated Emission Factor | Measured Emission Factor | (a) % Difference |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | Feb-23-78 | 100 | Panstar | 4.1 | 104 | 4.9 | 30 | 2.76 | 3.43 | -19.5% |
| 21 | May-26-78 | 53.3 | Arco Heritage | 7.6 | 63 | 5.1 | 1.3 | 1.40 | 0.93 | 50.1% |
| 22 | May-26-78 | 53.3 | Arco Heritage | 7.6 | 63 | 5.1 | 1.4 | 1.40 | 0.22 | 537.0% |
| 23 | May-26-78 | 53.3 | Arco Heritage | 7.6 | 63 | 5.1 | 1.3 | 1.40 | 0.87 | 60.5% |
| 24 | Feb-5-78 | 73 | Amoco Brisbane | 4.8 | 70 | 3.2 | 2.6 | 1.03 | 1.64 | -37.0% |
| 25 | Feb-5-78 | 73 | Amoco Brisbane | 4.8 | 70 | 3.2 | 2.6 | 1.03 | 1.79 | -42.3% |
| 26 | Feb-5-78 | 73 | Amoco Brisbane | 4.8 | 70 | 3.2 | 14.7 | 1.42 | 2.05 | -30.7% |
| 27 | Jul-20-78 | 78 | Amoco Yorktown | 4.4 | 87 | 4 | 5 | 1.31 | 1.43 | -8.4% |
| 28 | Jul-20-78 | 78 | Amoco Yorktown | 4.4 | 87 | 4 | 4.6 | 1.29 | 1.44 | -10.1% |
| 29 | Jul-20-78 | 78 | Amoco Yorktown | 4.4 | 87 | 4 | 4.9 | 1.31 | 0.91 | 43.5% |
| 30 | Nov-6-77 | NR | BURMA SPAR | 7.1 | 83 | 6.6 | 5 | 1.96 | 1.38 | 42.0% |
| 31 | Nov-6-77 | NR | BURMA SPAR | 7.1 | 83 | 6.6 | 15 | 2.62 | 0.69 | 279.7% |
| 32 | Nov-6-77 | NR | BURMA SPAR | 7.1 | 83 | 6.6 | 5 | 1.96 | 1.76 | 11.4% |
| 33 | Feb-14-78 | 70 | Esso Philippines | 7.8 | 42 | 3.6 | 2.2 | 1.11 | 0.83 | 33.6% |
| 34 | Feb-14-78 | 70 | Esso Philippines | 7.8 | 42 | 3.6 | 2.4 | 1.12 | 0.93 | 20.0% |
| 35 | Feb-14-78 | 70 | Esso Philippines | 3.7 | 45 | 1.3 | 3 | 0.61 | 0.41 | 48.5% |
| 36 | Apr-30-78 | NR | /T SINGAPURA KED | 5.5 | 76 | 4.2 | 4.8 | 1.35 | 0.98 | 37.9% |
| 37 | Apr-30-78 | NR | /T SINGAPURA KED | 5.5 | 76 | 4.2 | 4.8 | 1.35 | 0.96 | 40.8% |
| 38 | Apr-30-78 | NR | /T SINGAPURA KED | 5.5 | 76 | 4.2 | 4.8 | 1.35 | 1.64 | -17.6% |
| 39 | Jun-4-78 | 66.5 | Chev. JEGosline | 0.7 | 121 | 1.4 | 2.6 | 0.63 | 0.75 | -16.5% |
| 40 | Jun-4-78 | 66.5 | Chev. JEGosline | 0.7 | 121 | 1.4 | 2.5 | 0.63 | 0.64 | -2.3% |
| 41 | Oct-31-77 | 121 | Mobil Arctic | 4 | 50 | 1.65 | 6.5 | 0.75 | 0.51 | 46.5% |
| 42 | Oct-31-77 | 121 | Mobil Arctic | 4 | 50 | 1.65 | 6.5 | 0.75 | 0.71 | 5.2% |
| 43 | Oct-31-77 | 121 | Mobil Arctic | 4 | 50 | 1.65 | 12.5 | 0.85 | 0.72 | 17.5% |

Note:

(a) %-Difference = (Calculated - Measured)/Measured * 100

TABLE 5-15

CRUDE OIL BALLASTING EMISSIONS: MEASURED DATA vs. API MODEL PREDICTION

| Test Number | Date | Tanker MDWT | Tanker Name | RVP (psi) | Temp (F) | TVP (psi) | Arrival Ullage (ft) | Calculated Emission Factor | Measured Emission Factor | (a) % Difference |
|---|---|---|---|---|---|---|---|---|---|---|
| 44 | Jan-25-78 | 120 | Arco Anchorage | 3.9 | 55 | 1.75 | 0.9 | 0.68 | 0.95 | -28.9% |
| 45 | Jan-25-78 | 120 | Arco Anchorage | 3.9 | 55 | 1.75 | 1.8 | 0.69 | 0.96 | -28.0% |
| 46 | Apr-26-78 | 120.6 | Arco Juneau | 4 | 59 | 2 | 1.4 | 0.74 | 0.8 | -7.8% |
| 47 | May-24-78 | 49 | Exxon Baltimore | 4.2 | 110 | 5.5 | 5 | 1.69 | 2.4 | -29.8% |
| 48 | May-24-78 | 49 | Exxon Baltimore | 4.2 | 110 | 5.5 | 1.5 | 1.49 | 2.1 | -28.9% |
| 49 | May-24-78 | 49 | Exxon Baltimore | 4.2 | 110 | 5.5 | 8.4 | 1.87 | 2.7 | -30.7% |
| 50 | Jul-26-78 | 42.36 | Texaco Iowa | 3.3 | 122 | 5.3 | 5 | 1.64 | 2.3 | -28.9% |
| 51 | Jul-26-78 | 64.635 | Texaco Venezuela | 4.4 | 132 | 2.4 | 27.7 | 1.45 | 2.8 | -48.0% |
| 52 | Jul-26-78 | 64.635 | Texaco Venezuela | 4.4 | 132 | 2.4 | 4.7 | 0.90 | 4.3 | -79.0% |
| 53 | Jan-24-78 | 111 | Yorkshire | 4.7 | 74 | 3.3 | 2 | 1.04 | 1.42 | -27.0% |
| 54 | Jan-24-78 | 111 | Yorkshire | 4.7 | 74 | 3.3 | 2 | 1.04 | 1.7 | -39.1% |
| 55 | Mar-11-78 | 85 | Atomic | 2.9 | 65 | 1.55 | 4 | 0.68 | 3.79 | -82.0% |
| 56 | Mar-11-78 | 85 | Atomic | 2.9 | 65 | 1.55 | 21 | 0.95 | 3.64 | -74.0% |
| 57 | Mar-11-78 | 85 | Atomic | 2.9 | 65 | 1.55 | 5.25 | 0.70 | 3.05 | -77.0% |
| 58 | Mar-2-78 | 49.88 | Texaco Utah | 4.8 | 62 | 2.7 | 1.5 | 0.89 | 1.29 | -31.0% |
| 59 | Mar-2-78 | 49.88 | Texaco Utah | 4.8 | 62 | 2.7 | 1.42 | 0.89 | 1.35 | -34.2% |
| 60 | Mar-21-78 | 49.88 | Texaco Utah | 4.6 | 66 | 2.8 | 1.25 | 0.91 | 1.18 | -23.3% |
| 61 | Mar-21-78 | 49.88 | Texaco Utah | 4.6 | 66 | 2.8 | 1.42 | 0.91 | 0.86 | 5.8% |
| | | | | | | AVERAGES: | | 1.37 | 1.55 | 16.3% |
| | | | | | | ABSOLUTE AVERAGE: | | | | 49.9% |

Note:

(a) %-Difference = (Calculated - Measured)/Measured * 100

Section 6

# Validity and Application of API Emission Estimates

An assessment was made as to the validity and application of the API crude oil loading emission estimation techniques in light of the new Valdez, Alaska, crude oil loading emission tests conducted for the Alyeska Pipeline Service Company. The assessment is based on a review of the literature obtained, discussions with API member companies, and a comparison of API, ARCO Plano, and EXXON crude oil loading emission estimation models (Tasks 1 and 2). The crude oil loading emission estimates are the focus of this section since essentially no new gasoline loading and crude oil ballasting emission test data were obtained during the literature search phase of the project.

As discussed in Section 5, a comparison test data base consisting of a representative sample of the Alyeska test data (25 out of the 80 tests) and essentially all the available Ventura County tests used to develop the API model, were used to quantitatively and graphically assess the validity of the API model.

As indicated in Section 4, emissions from crude oil loading operations are comprised of an arrival and generated emission component. The arrival component is principally based on the volatility of the prior cargo of the tank compartment and the ballast voyage compartment treatment. Crude oil washing of the compartment(s) before loading would also contribute to the arrival emission component. Test data incorporating crude oil washing were not included in the API correlations. The generated component is principally based on the mass transfer of volatile components through the gas/oil interface within the cargo compartment into the vapor space. Diffusion and convection are the primary mechanisms contributing to these generated emissions.

## 6.1 Test Data Base/Model Summary

The API crude oil loading emission model was based principally on the lower 48 state (Ventura County) test data covering a limited size range of tankers (17,000 to 35,000 dwt). The model correlations did not include barge data.

The API model indicates that the generated emission component is a direct function of the TVP of the crude oil being loaded. The temperature of the loaded crude, the vapor growth factor, and the average vapor molecular weight of the crude are also needed to estimate the generated emission component. The arrival component is a single factor based on the prior cargo volatility and the prior compartment treatment. The test data were averaged according to a prior cargo/compartment treatment category to develop the resultant arrival component in the API model.

The ARCO Plano crude oil loading emission model was based on tanker test data from Valdez, Alaska. The tested tankers ranged in size from 75,000 to 265,000 dwt. The model correlations did not include barge data.

The ARCO Plano emission model does not directly base the generation emission on TVP; instead it develops an equation based on the surface area of the cargo compartment(s) being loaded, the loading time, the volume of crude being loaded, and the crude loading temperature. The arrival component is principally based on the percent hydrocarbon in the arrival compartment(s) and the volume of vapor displaced by the loaded crude.

The EXXON emission estimating model was based mainly on motor gasoline loading data for EXXON's facility in Baytown, Texas. Some crude oil loading data were also included from Iran. The model is applicable to both gasoline and crude oil loading operations. Parametric equation correlations were based mainly on tested tankers ranging in size from 39,000 to 76,000 dwt. Tested barges less than 10,000 dwt were also included in the correlations.

The EXXON emission estimation model incorporates the cargo surface area, TVP, a derived hydrocarbon generated coefficient, and the final true ullage into the generated emission component expression. In addition, as with the ARCO model, the arrival component is based on the percent hydrocarbon in the arrival compartment(s) and the volume of vapor displaced (volume of crude loaded).

The sampling and analytical procedures used to estimate crude oil loading emissions from Alaska and from the lower 48 states (the Alyeska, API, and EXXON test data bases) generally followed API guidelines. A brief review of the QA/QC procedures indicated that the measured emission results were of sufficient quality to be used in developing predictive emission models.

Only a limited range of tankers sizes (no VLCCs) were included in API data base. These data could be well supplemented with the significantly wider range of tanker sizes in the Alyeska test data base. In addition, test data on barges would improve the accuracy of the API model since barges have a greater cargo surface area to volume ratio, which suggests a greater generated emission per volume of crude loaded than that indicated for tankers.

## 6.2 Review of Parameters Affecting Generated Component Emissions

Based on an evaluation of test data from Alyeska and the lower 48 states (API data) and from the review of available literature, it can be concluded—as indicated in the API model—that the TVP of the crude being loaded is functionally related to the generated emissions. Figure 6-1 graphically supports this conclusion. Although a direct relationship cannot be ascertained from the curve, it does indicate that, in general, generated emissions increase as TVP increases.

Preliminary results from a recent crude vapor pressure study by Alyeska (to be completed in 1992), indicate that the TVP (of Alaskan crude), as determined by the API model nomograph may underestimate the "actual" TVP by 2 to 2.5 psia. If this is verified, it could help account for the apparent underestimation of Alyeska's generation emissions by the API model.

As discussed in Section 5, the measured generated emission data from Valdez, Alaska, (i.e., the Alyeska data that were used to correlate the ARCO Plano model) are consistently higher than that predicted by the API model. The API model was based on an linear equation derived from the ideal gas law and fitted with test data from Ventura County, California. The higher measured test data from Alaska may occur in part because of the convection currents produced from the larger difference between crude loading temperatures and compartment vapor temperatures typically encountered in colder climates such as Alaska. Figure 6-2 graphically presents the relationship between measured generated emissions and temperature difference (crude oil loading temperature minus vapor temperature). The curve suggests that generated emissions increase as the temperature difference increases. The Alyeska data clearly have the higher generated emissions which, in part, appear to be associated with larger differences between crude oil loading and vapor temperature encountered in Alaska.

Cargo surface area and the loading rate (or time) also contribute to emissions generation. However, a functional relationship between these two parameters and generated emissions could not be graphically demonstrated (Figure 6-3 and 6-4). Cargo surface area appears to be indirectly included in the API crude oil equation (in terms of the initial and final ullage and tank compartment volumes used in the mass balance vapor growth equation). However, loading time or rate is not included in the derivations. The ARCO Plano model uses both of these parameters directly.

Although the differences between cargo surface area and loading rate measured for the Alyeska and API test data bases may not account for the difference between measured Alyeska and predicted API emissions, it does suggest that a parametric equation incorporating surface area and loading rate may improve the overall accuracy of the API crude oil loading emission model.

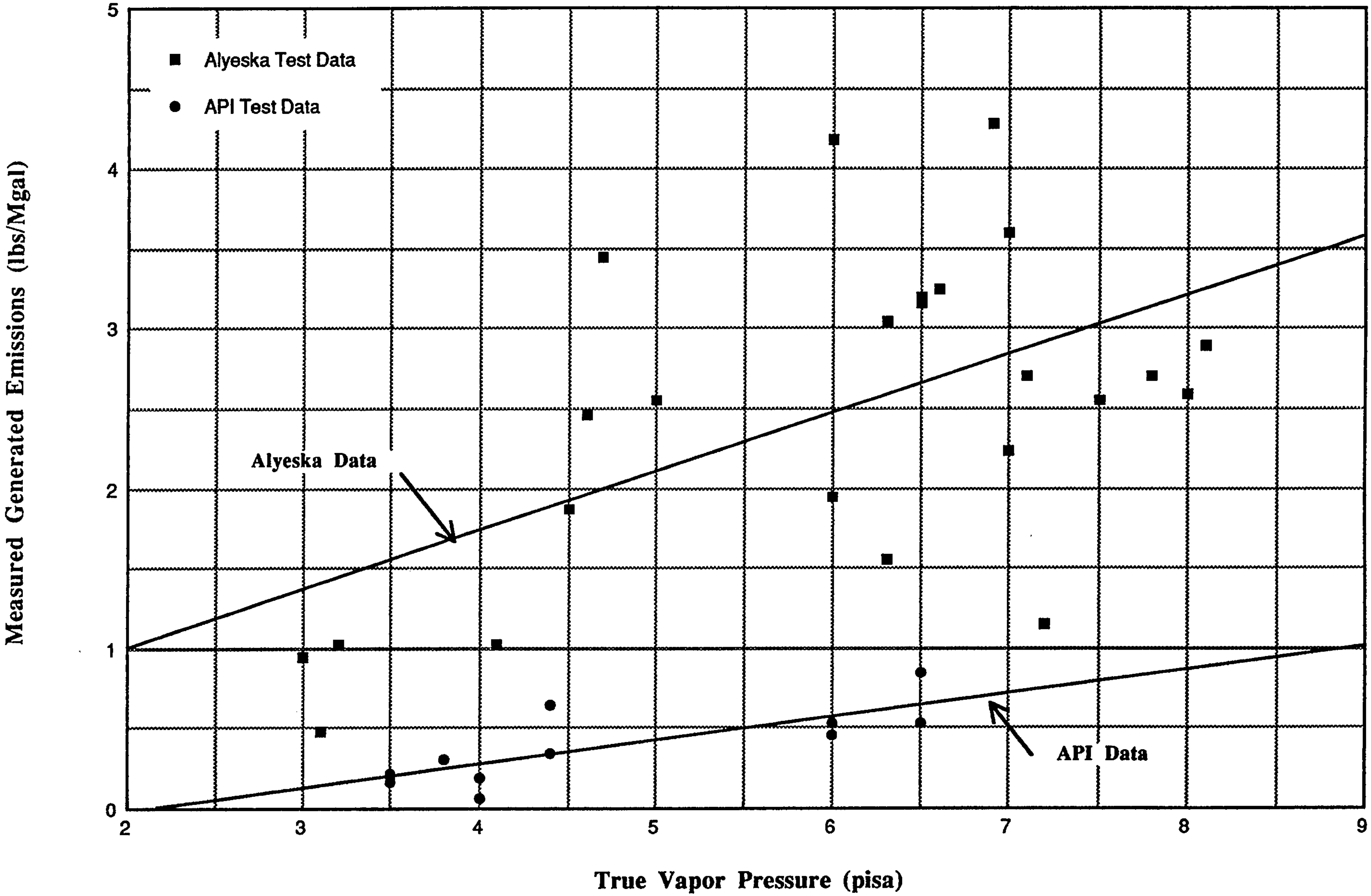
Review of the literature and discussions with API member companies suggest that the crude oil loading temperature has a direct impact on generated emissions. Figure 6-5 graphically presents the relationship between measured generated emissions and crude loading temperature. Although a direct relationship is not readily apparent from this curve, it does indicate that, overall, generated emissions increase as crude loading temperature increases.

The review also suggests that a functional relationship exists between generated emissions and tanker configuration. This relationship, however, is considered to be minor.

# Figure 6-1

## Crude Oil Loading

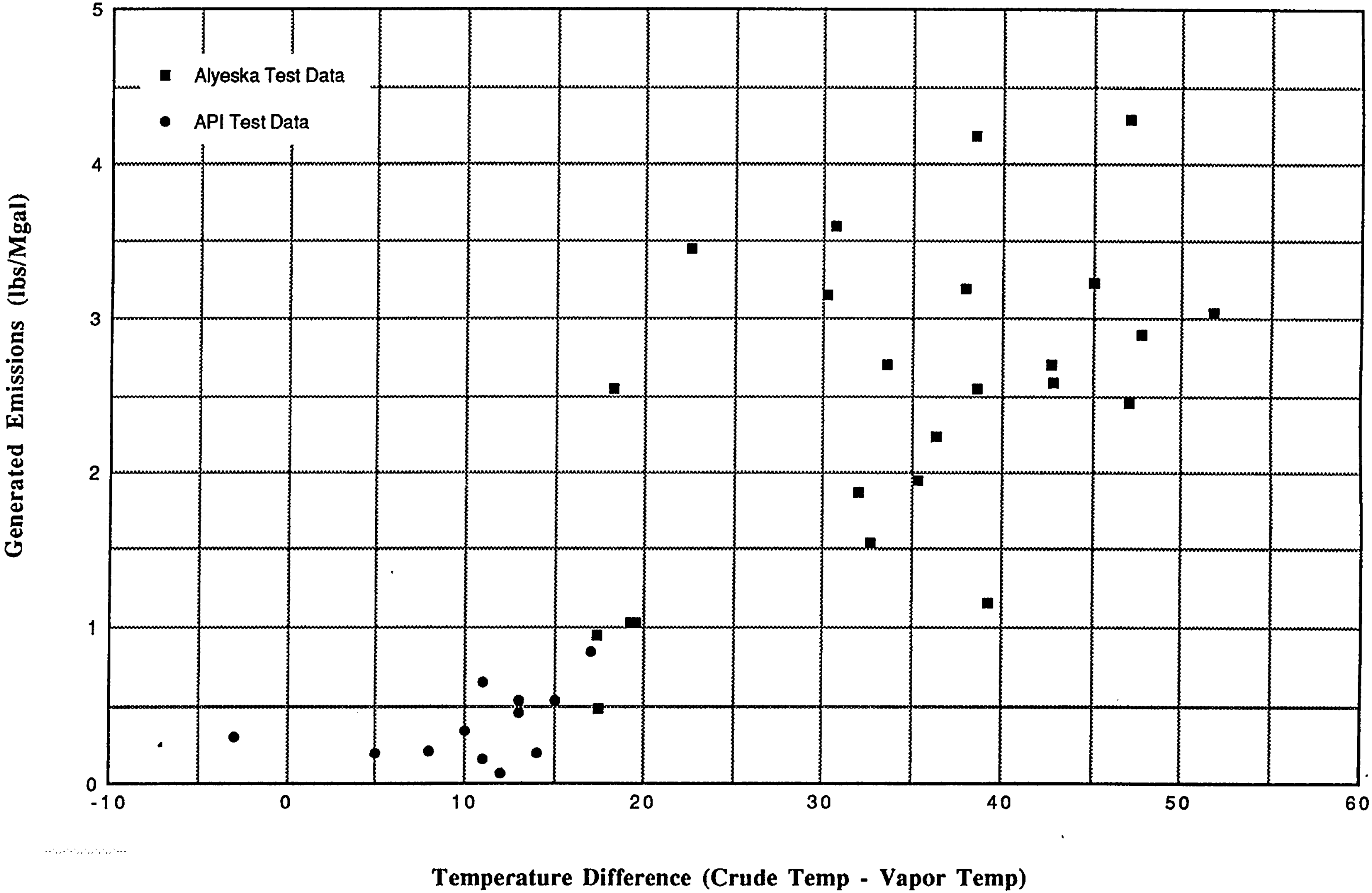
## Measured Generated Emissions Versus True Vapor Pressure



# Figure 6-2

## Crude Oil Loading

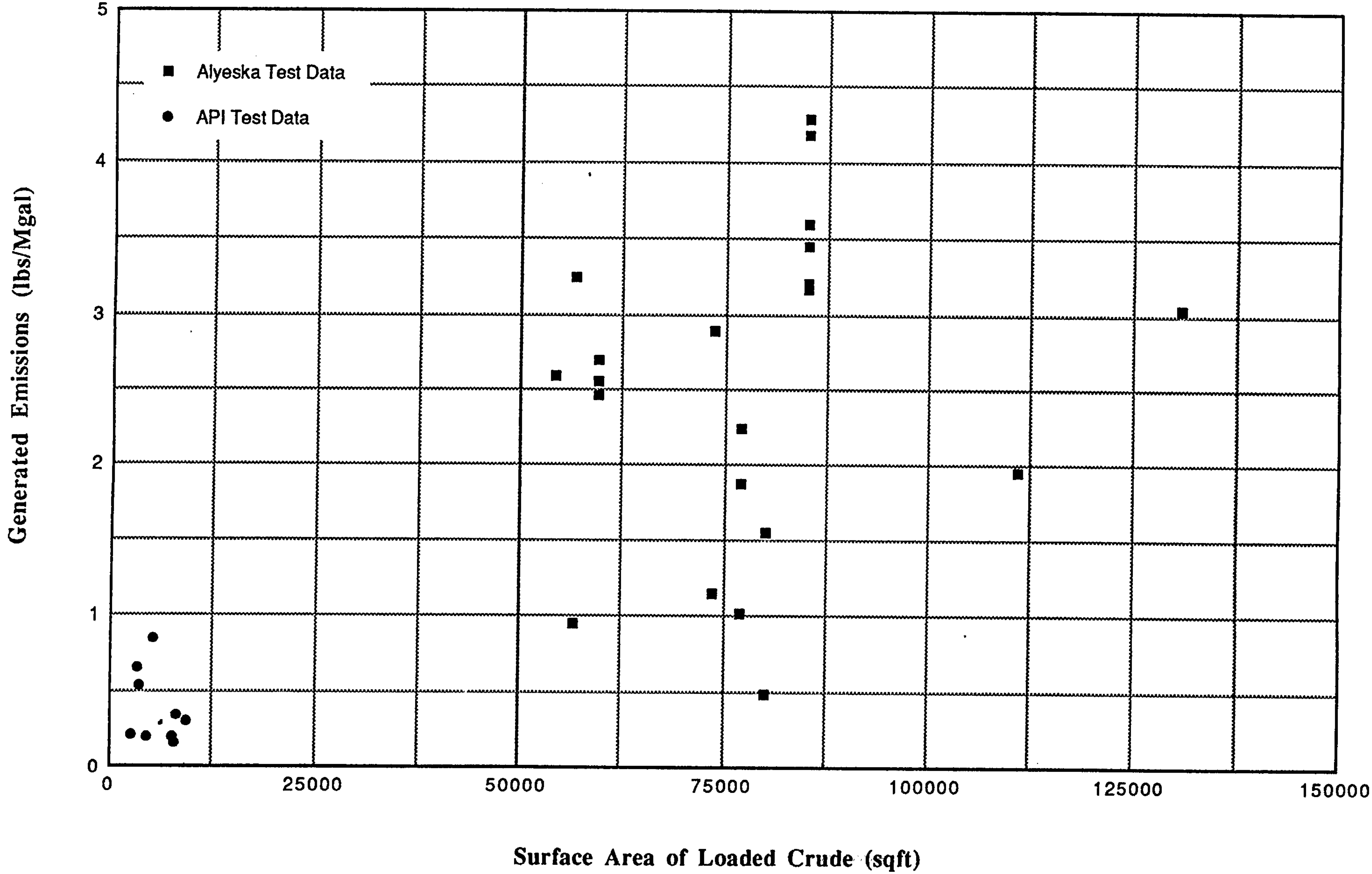
## Measured Generated Emissions Versus Loaded Temperature Difference



# Figure 6-3

## Crude Oil Loading

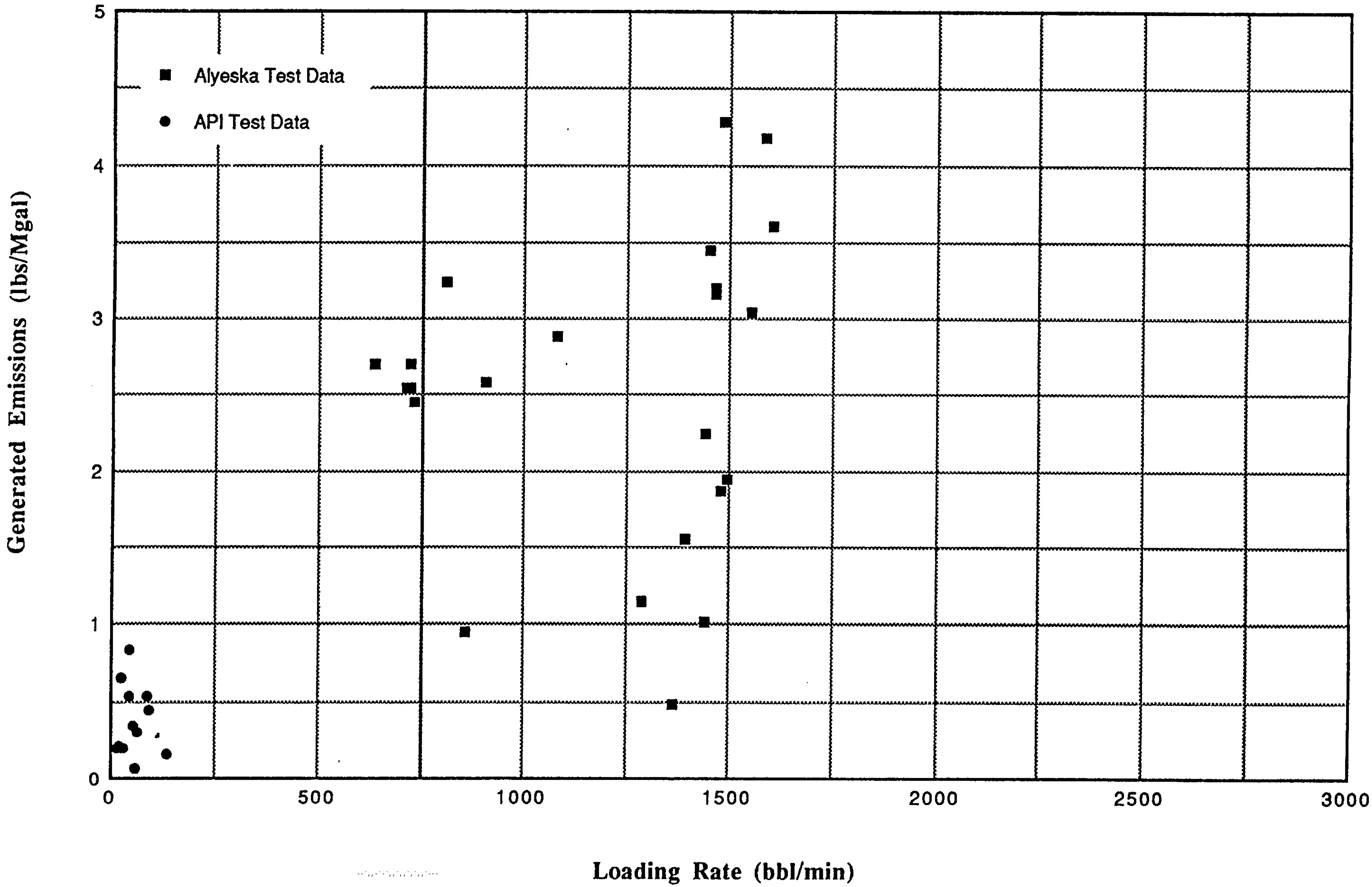
## Measured Generated Emissions Versus Surface Area



# Figure 6-4

## Crude Oil Loading

## Measured Generated Emissions Versus Loaded Rate



# Figure 6-5

## Crude Oil Loading

## Measured Generated Emissions Versus Loaded Crude Temperature

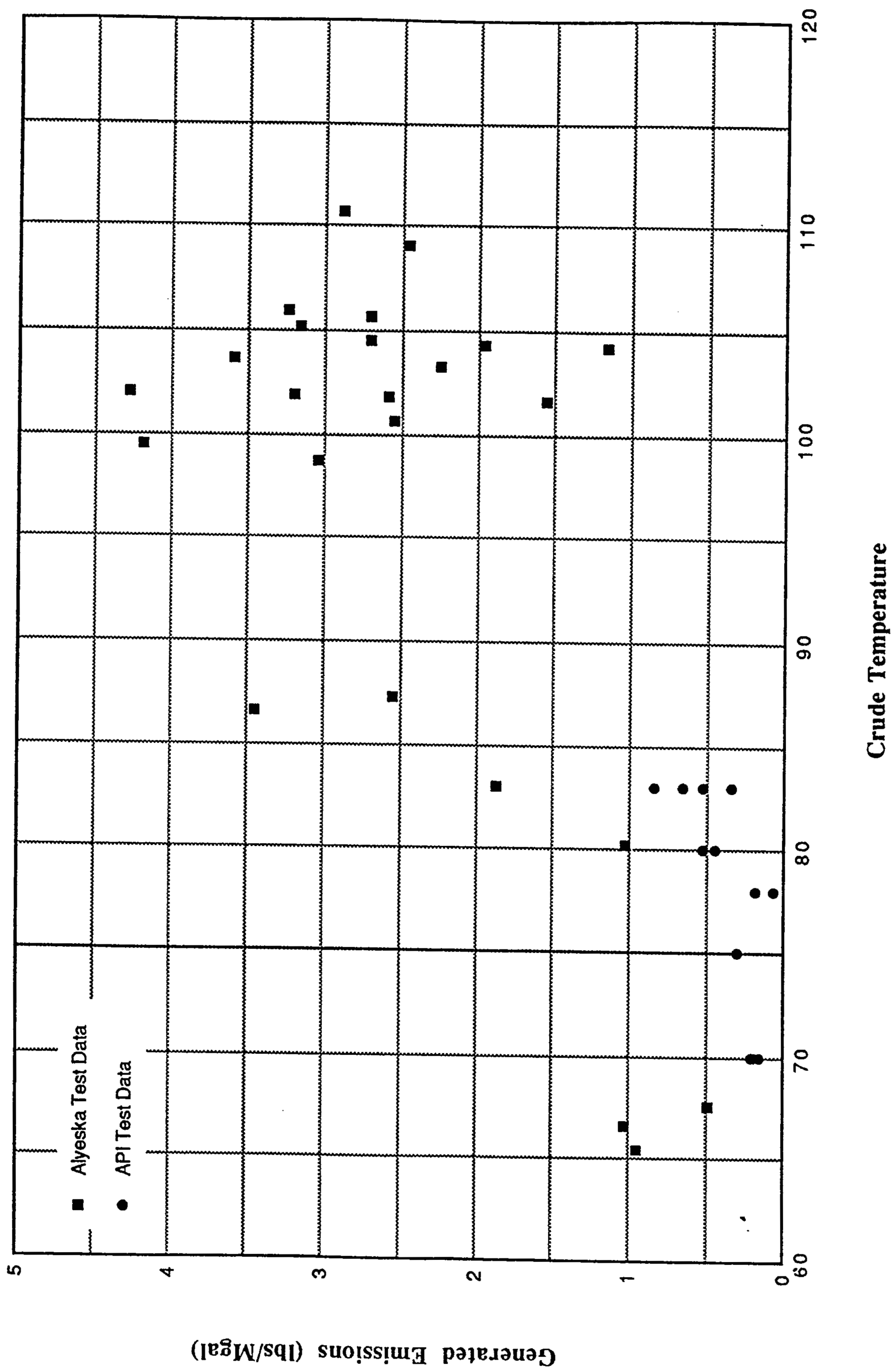


Figure 6-6 tends to support the conclusion that all other parameters being equal, generated emissions increase with increased dwt. However, the other parameters discussed previously appear to have a greater impact on generated emissions.

Although a functional relationship apparently exists between the TVP of the loaded crude and the generated emissions, TVP may not be a direct indicator of emissions. The lighter ends of the crude (methane, ethane, propane) principally contribute to the TVP, however, they do not contribute significantly to the generated emissions on a weight basis. As a result, knowledge of the composition of various crude oils may help determine an "effective volatility" parameter for inclusion in a revised emission model. The impact of the use of "effective volatility" instead of TVP is probably minor compared to the effect the cargo surface area and temperature-driven convection currents have on the generated emission component. This apparently minor impact was supported by the fact that the Alaska crude was spiked with NGL. The Alyeska report (1990) indicated that lowering the NGL content in the crude did not appreciably impact the generation of hydrocarbon emissions.

Other parameters, such as the extent to which the cargo compartment is filled, apparently have only a minor impact on generated emissions.

## 6.3 Review of Parameters Affecting Arrival Component Emissions

A portion of the compartments from each tanker from the Alyeska test data base underwent crude oil washing before conducting the crude loading emission tests. Crude oil washing was apparently not employed in the Ventura County tanker test data base used to correlate the API model. Figure 6-7 graphically presents the measured arrival emissions from the Alyeska test data as a function of the percent of cargo compartments crude oil washed. It should be noted that most of the Alyeska tankers tested had a header and mast riser venting system. Therefore, the measured emissions were for the tanker as a whole, not for individual compartments. Each data point from Figure 6-1 represents total tanker arrival emissions.

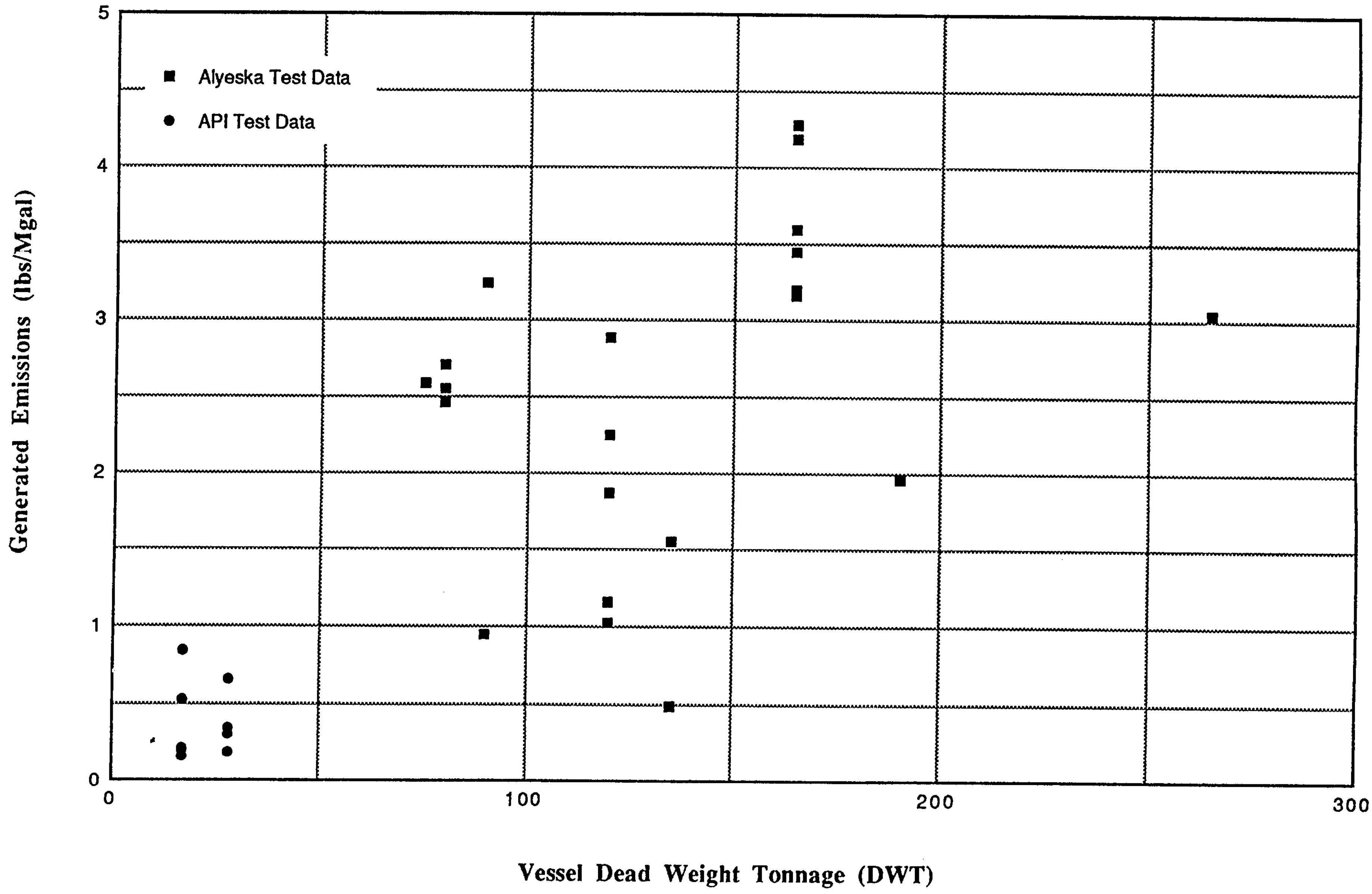
Although a defined relationship between arrival emissions and percent of compartments crude oil washed cannot be ascertained from this curve, it does indicate that arrival component emissions in excess of 0.86 lb/1,000 gallons (API's highest arrival component) occur at the Valdez Terminal. Other factors such as prior cargo volatility and tanker configuration also play a role in the magnitude of arrival emissions.

As previously stated, API currently does not incorporate VLCCs or crude oil washed compartments into its model. Incorporating VLCCs and crude oil washed compartments into the arrival component correlation could help strengthen the overall reliability of the API model.

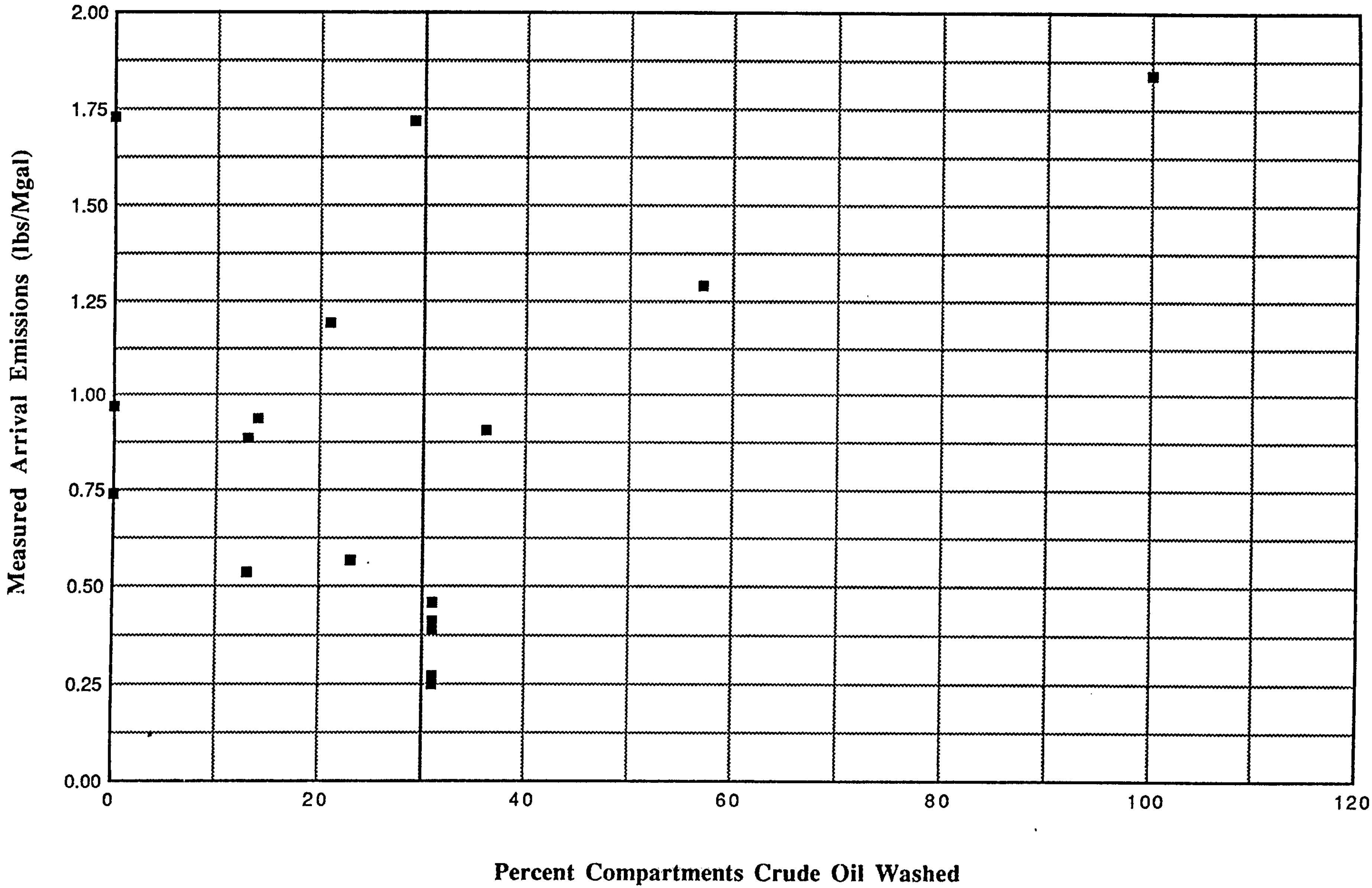
# Figure 6-6

## Crude Oil Loading

## Measured Generated Emissions Versus Dead Weight Tonnage



# Figure 6-7
## Crude Oil Loading
## Measured Arrival Emissions Versus Percent Cargo Space Crude Oil Washed
### Alyeska Data Only



## 6.4 Review of API Crude Oil Loading Model Equation

As discussed in Section 4, the API crude oil loading emission model is based on the following equations derived from the ideal gas law:

(1) Et = 1.84 (MaCa + MgCg) G / T
(2) Eg = 1.84 (MgCg) G / T

where:

Et = the total crude oil loading emissions in pounds per 1,000 gallons

Eg = the generated emission component in pounds per 1,000 gallons

Ma = the average molecular weight of the arrival vapor

Ca = the average percent hydrocarbon concentration in the arrival vapor

Mg = the average molecular weight of the generated vapor

Cg = the average percent concentration of hydrocarbon in the generated vapor

G = the vapor growth factor (dimensionless), which is the additional vapor generated as a result of loading crude

T = the average vapor temperature of the vented crude

According to the ideal gas law, the term MaCa + MgCg should be equivalent to the average molecular weight of the total vented vapor multiplied by the average percent hydrocarbon in the total vented vapor (call it MvCv). MvCv would typically fall between MaCa and MgCg since the hydrocarbon concentration in the arrival vapor (vapor vented during the initial stages of the crude loading cycle) are very small compared to the hydrocarbon concentration in the generated vapors (vapor vented near the end of the crude loading cycle). As a result, the Et function would be based on a fraction (f) of the MaCa + MgCg term. The revised form of the Et and Eg equations could therefore be:

Et = 1.84 (f) (MaCa + MgCg) G / T and

Eg = 1.84 (f) (MgCg) G / T.

As also indicated in Section 4, the final version of the API generated emission equation was based on correlating TVP from the test data base to the average percent hydrocarbon in the generated vapors (Cg). As a result, a revised final generated emission equation could take on a recorrelated expression for Cg, which is based on a larger test data base and incorporates parameters such as TVP (or some derived effective volatility relationship), cargo surface area, crude loading time, and crude/vapor temperature differentials.

The API documentation file indicates that the vapor growth factor used in the API model was determined from the difference between the total volume of vented vapor and the volume of vapor displaced by the incoming crude. A mass balance based on initial and final ullage differences, crude volumes, and hydrocarbon concentrations was used to calculate the total volume of vented vapor. The original test data calculations, as documented in WOGA (1977), determined vented volume (and in turn vapor growth) from a mass balance of arrival inert gas and final inert gas vented plus that remaining in the final ullage. Flow rate measurements were not taken during the Ventura County testing.

The WOGA test report stated that the vapor growth factors for the Ventura County tanker tests were approximately 2 percent. Using the ullage difference mass balance calculation in the API documentation file resulted in vapor growth factors ranging from 5 to 20 percent. It is difficult to ascertain the difference between the API and the WOGA test report calculation methods. It is suggested that the determination of vapor growth be reassessed to understand this apparent discrepancy. (It should be noted that the Alyeska test report also used a mass balance approach for calculating vented volume and vapor growth in lieu of measuring flow rates. However, the mass balance approach was verified with flow rate measurements before conducting the tests.)

Section 7
# Recommendations for Improving the Validity of the API 2514A Emission Estimates

The following recommendations are provided for the improvement of the API emission estimation models. They are based on a review of the available literature, discussions with API member organizations, and direct comparisons of predicted and measured emissions.

## 7.1 Crude Oil Loading Emissions

It is recommended that the arrival and generated emission components be recorrelated to include both the original Ventura County, California (WOGA), and the Alyeska test data. By so doing, the test data base used in the revised API equation would be based on a substantially larger range of tanker sizes (including VLCCs) that are more representative of the fleet population. Including the Alyeska data would also incorporate compartments that have been crude oil washed.

It is suggested that the test data be fit to a revised parametric equation for at least the generated emission component. Because of the variability in arrival conditions, the use of a single factor averaged according to prior cargo volatility/prior compartment treatment may still be appropriate. However, the development of a parametric equation (based on the percent hydrocarbon in the arrival compartments) would be preferred if statistically significant trends develop during model correlation.

It is recommended that parametric equations be developed which predict generated emissions according to two different levels of accuracy. The first equation would be based on TVP (or an equivalent effective volatility measure), vapor growth, and vapor temperature, and essentially follow the form of the existing API equation which is derived from the ideal gas law. As discussed in Section 6, an adjustment to the API equation would be needed to correct the apparent error in the molecular weight and the hydrocarbon concentration terms (MgCg). In addition, a consistent method to calculate the vented volume and vapor growth would need to be developed. This revised equation would be the user-friendly version of the two parametric equations.

The second parametric equation to be developed for the generated emission component would be based on the inclusion of other parameters that have that have a significant impact on the generation of emissions. This approach would incorporate many of the elements of the mechanistic models developed by ARCO Plano, BP, and EXXON. Additional parameters to be included in the development of this more detailed (and potentially more accurate) equation would include:

1. Crude loading temperature

2. Crude loading rate
3. Difference between crude loading and vapor temperature
4. Cargo surface area
5. Percent hydrocarbon in the vented vapor volume

A review of the Alyeska test data indicated that these parameters were on average higher for the tests reporting higher total crude oil loading emissions. This suggests that these parameters do contribute to the generation of emissions during crude oil loading operations.

Although it is recognized that this more detailed version of the equation may not be very user friendly, it would be important to make every effort to establish the parametric relationships needed to simplify its use (i.e., minimize the number of variables needed in the equation).

It is also recommended to include hazardous air pollutants such as benzene into the crude oil loading emission estimates. This potentially could entail the inclusion of a table summarizing the percentage of benzene in the hydrocarbon generated as a function of type of crude being loaded. This information could be obtained from crude light-end analyses performed at refineries. The Alyeska report measured generated and total benzene emissions for each of its crude oil emission tests.

## 7.2 Gasoline Loading Emissions

As additional test data become available, it is recommended that these data be included in a revised emission factor estimate.

## 7.3 Crude Oil Ballasting Emissions

As part of future updates, it may be useful to recorrelate crude oil ballasting emissions by including parameters for vapor space volume and exposed surface area along with the volume of ballast water, ullage, and TVP already included in the correlation.

## Section 8
# References

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Western Oil and Gas Association. (Chevron Research Company.) *Hydrocarbon Emissions During Marine Loading of Crude Oils, Ventura County, California*. Richmond, California. August 1977.

## 8.1 Personal Communications

API
ARCO
Alyeska
Bay Area Air Quality Management District
British Petroleum
Chevron
EXXON
Shell
South Coast Air Quality Management District
Santa Barbara County Air Pollution Control District
Unocal

## Appendix A

# Crude Oil Loading Emissions/Comparison Test Data Base

The figures (bar charts) in this appendix were prepared to supplement Figures 5-1 through 5-3 in Section 5 of the test. The figures indicate the variability of measured emissions and predicted emissions according to the API, ARCO, and EXXON models.

# Figure A-1

## Crude Oil Loading

## Total Emissions

### Alyeska Test Data

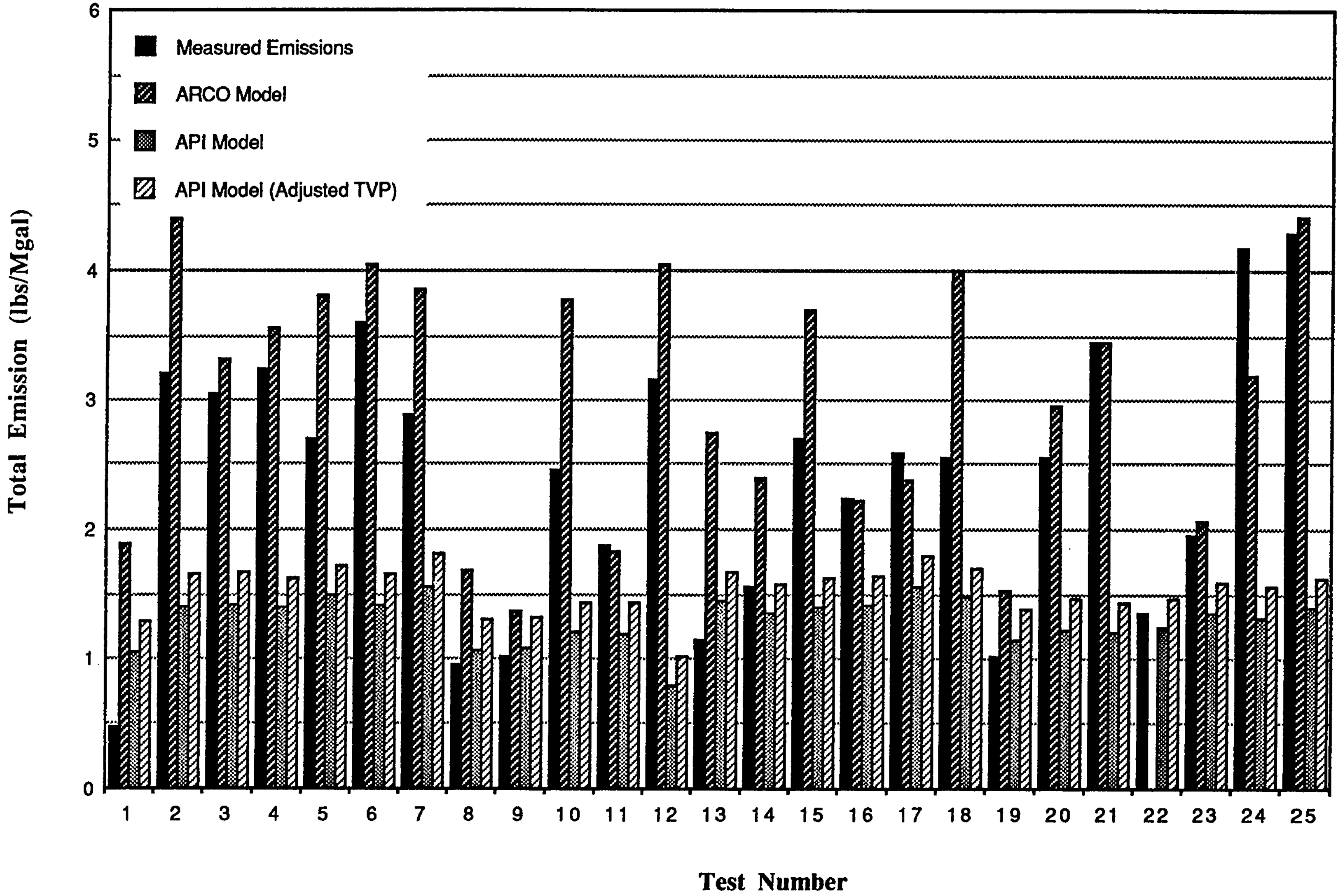
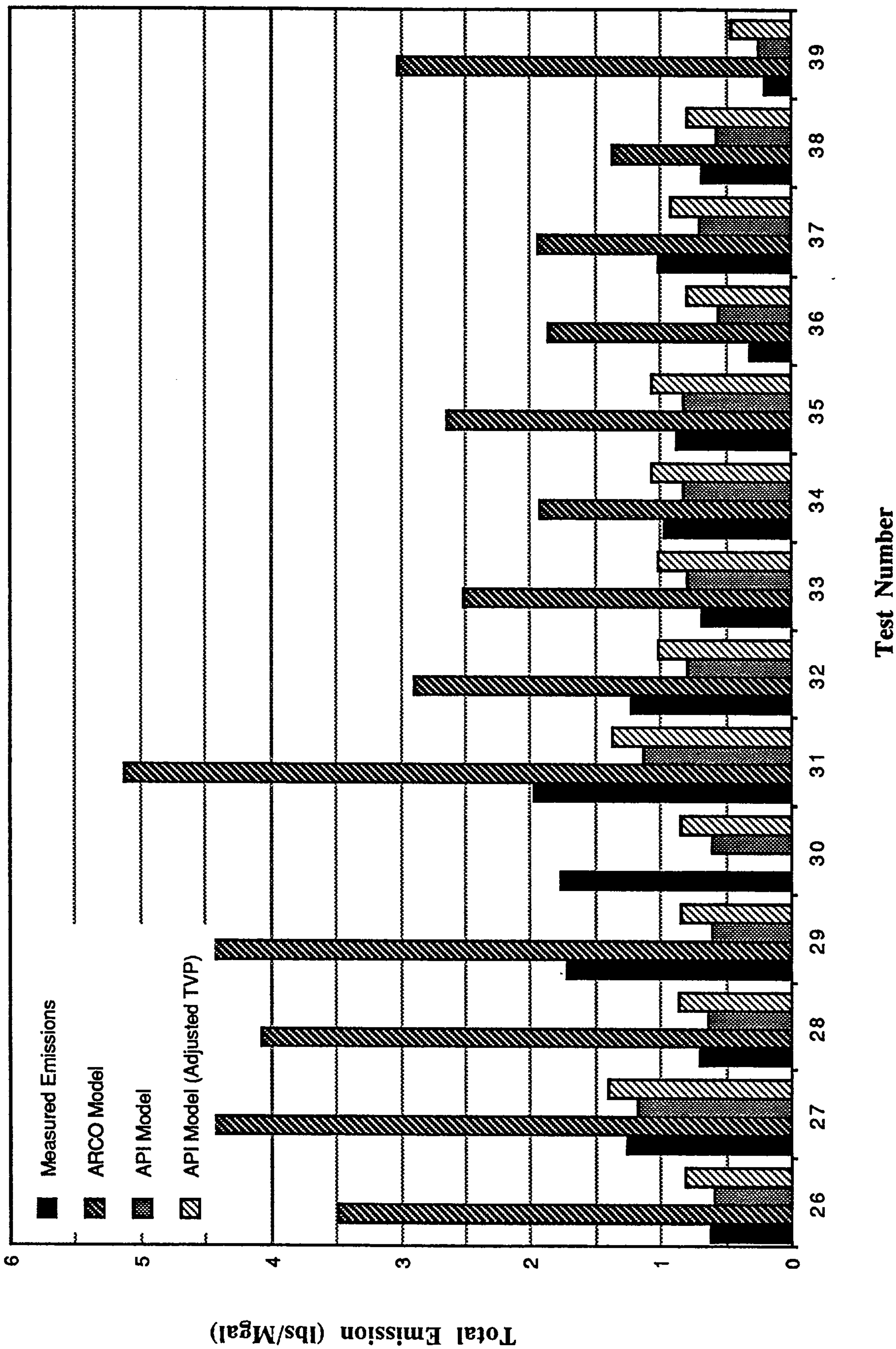
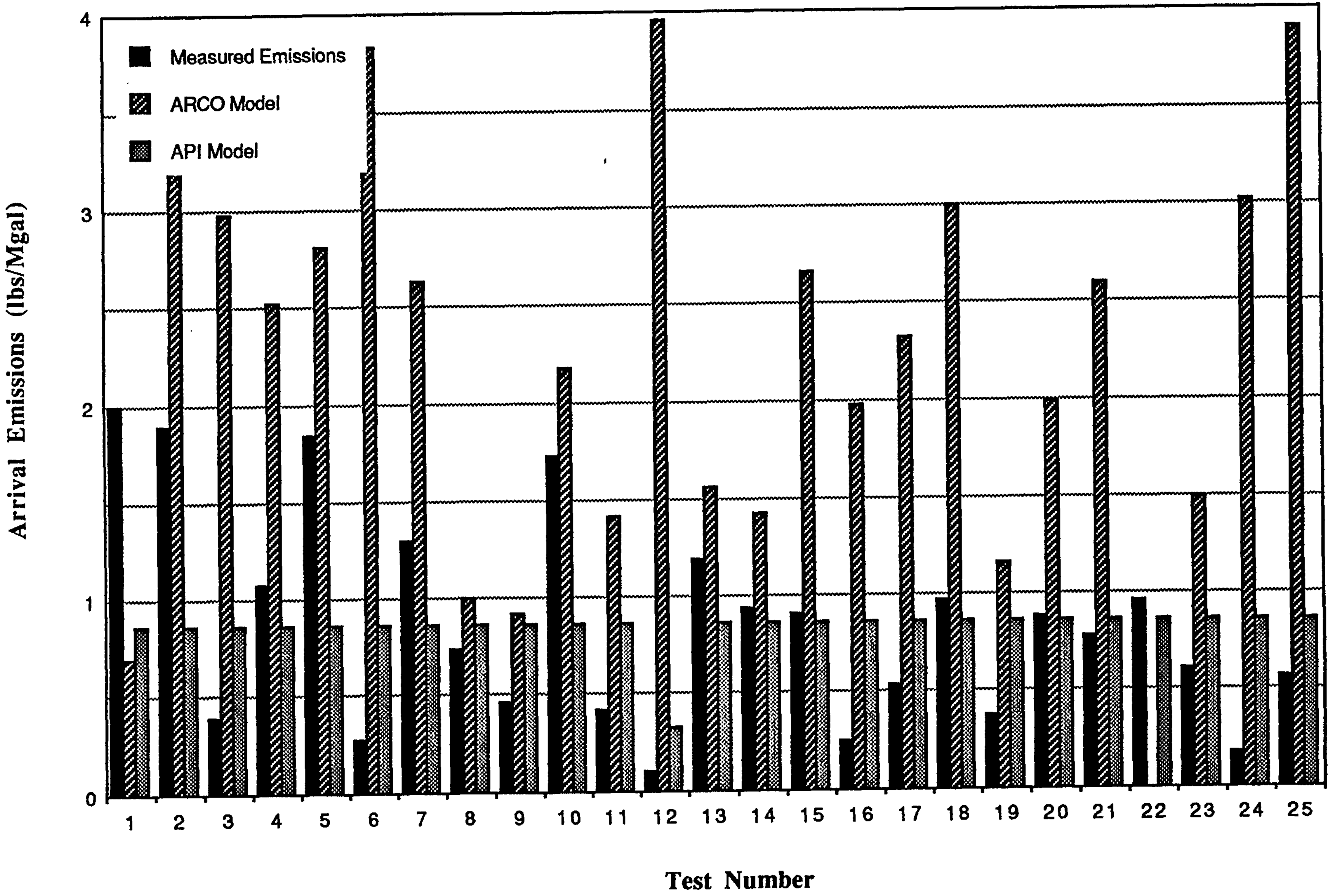


**Figure A-2**
**Crude Oil Loading**
**Total Emissions**

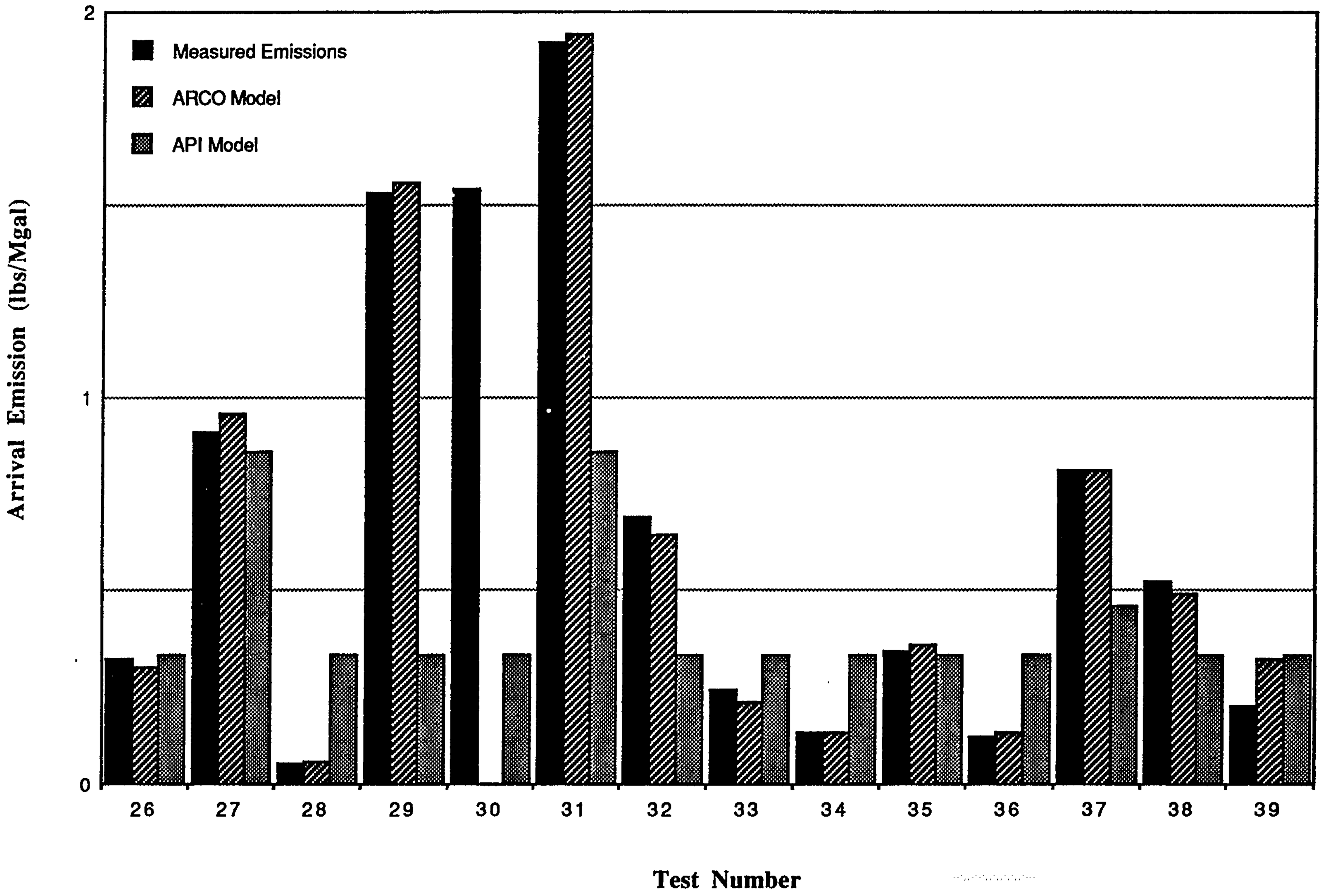
**API Test Data**



# Figure A-3
## Crude Oil Loading
## Arrival Emissions
### Alyeska Test Data



# Figure A-4
## Crude Oil Loading
## Arrival Emissions
### API Test Data



# Figure A-5
## Crude Oil Loading
## Generated Emissions
### Alyeska Test Data

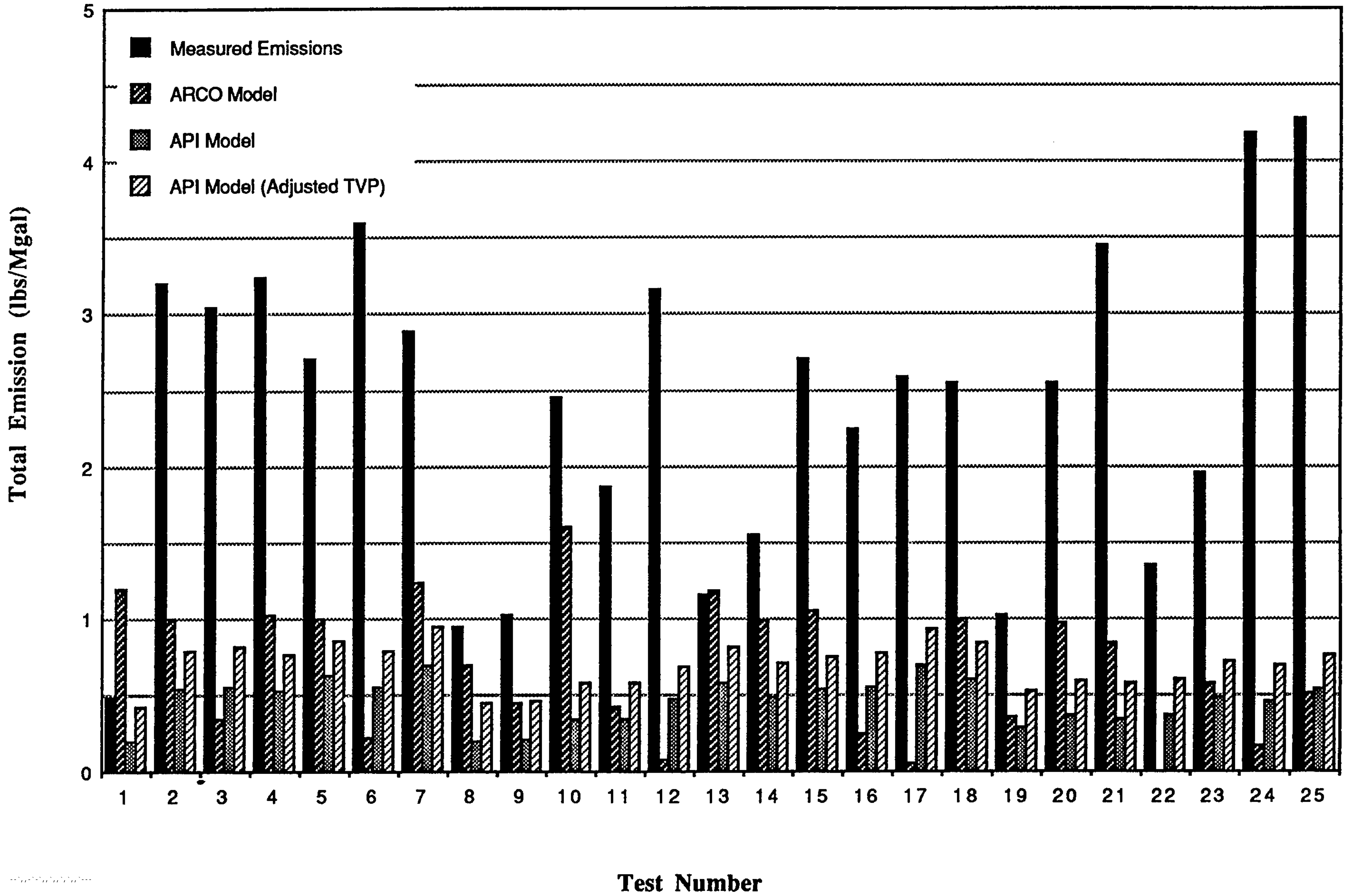
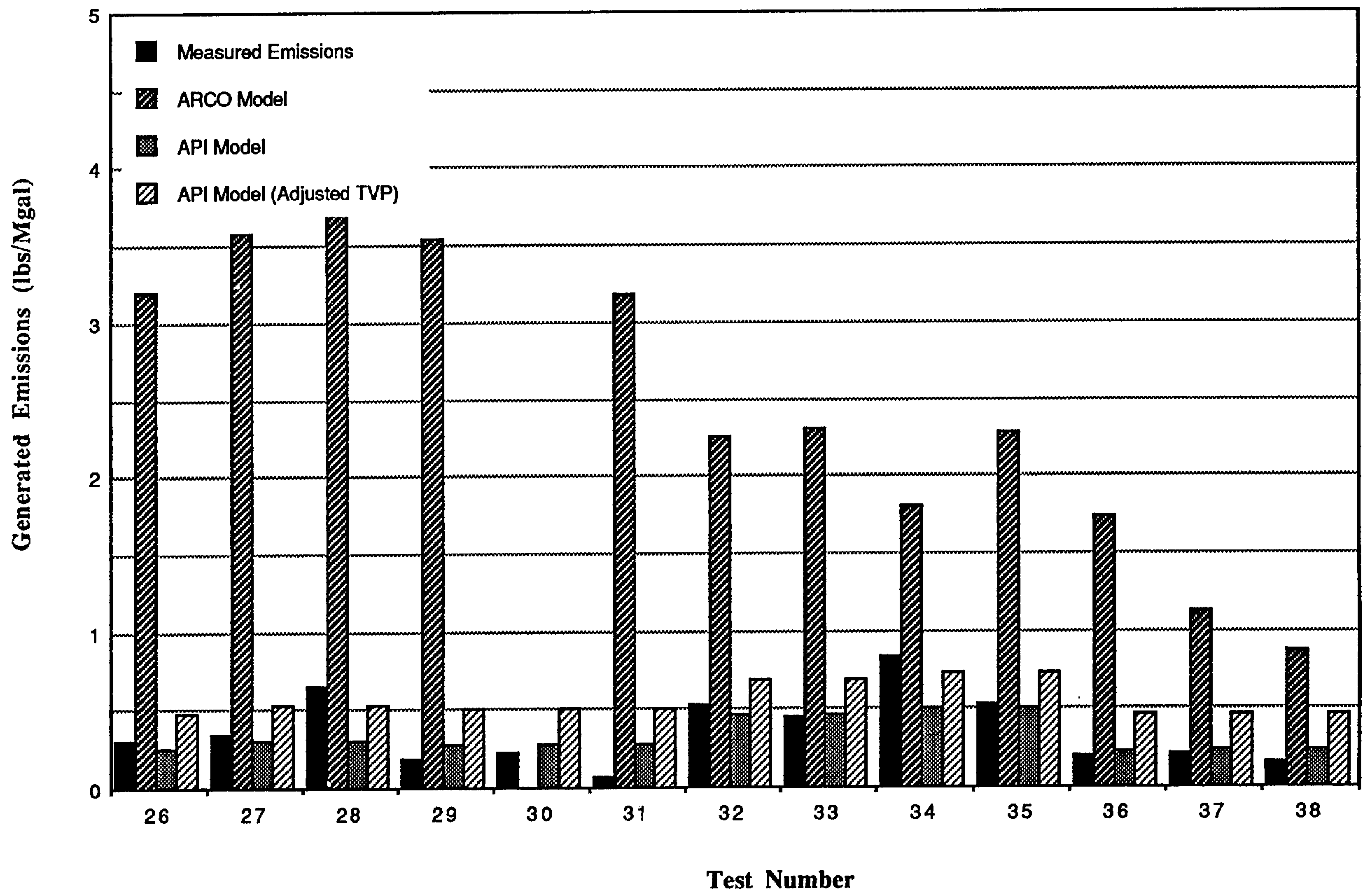


**Figure A-6**
**Crude Oil Loading**
**Generated Emissions**
**API Test Data**



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