Manual of Petroleum Measurement Standards
Chapter 19.3—Evaporative Loss Measurement

Part D—Fugitive Emission Test Method for the Measurement of Deck-Seam Loss Factors for Internal Floating-Roof Tanks

FIRST EDITION, JUNE 2001

REAFFIRMED, DECEMBER 2012

energy API

AMERICAN PETROLEUM INSTITUTE

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FOREWORD

This standard provides rules for testing the deck seams or deck joints of internal floating roofs under laboratory conditions to provide evaporative deck-seam loss factors or deck-joint loss factors. It was prepared by Task Group II of the API Committee on Evaporative Loss Estimation (CELE).

A testing program was conducted in 1982 that used the pilot tank test method for measuring the deck-seam loss factors of mechanically-joined, contact and non-contact internal floating roofs. The deck-seam loss factor that is published in API Publication 2519, *Evaporative Loss From Internal Floating-Roof Tanks*, and in API *Manual of Petroleum Measurement Standards*, Chapter 19.2, "Evaporative Loss From Floating-Roof Tanks," is based on these tests. This deck-seam loss factor and the test method that was used to develop it have been widely accepted by oil companies, manufacturers, industry groups, regulatory agencies, and general interest groups. API has not, however, tested or developed deck-seam loss factors for proprietary designs of individual manufacturers.

A second testing program was conducted in the period from 1994 through 1996 that used the weight loss test method for measuring deck-seam loss factors. These tests were directed at developing a test protocol that would eventually be published in the API *Manual of Petroleum Measurement Standards*, Chapter 19.3, Part C, "Weight Loss Test Method for the Measurement of Deck-Seam Loss Factors for Internal Floating-Roof Tanks." The first edition of this publication is still under development.

A third testing program was conducted in 1999 that used the fugitive emission test method for measuring deck-seam loss factors. These tests were directed at developing the test protocol that is described in this publication.

By publishing this fugitive emission test method, the API is making this test method available to interested parties who wish to test particular deck seams or deck joints under the auspices of the API.

API certification of an evaporative loss factor developed through this program is subject to the following three-step process:

a. The testing shall be performed in laboratories licensed by the API. The requirements to qualify for licensure are presented in the API Manual of Petroleum Measurement Standards, Chapter 19.3, Part G, "Certified Loss Factor Testing Laboratory Registration;"

b. Testing and determination of test results shall be performed as specified herein; and

c. The evaluation of these test results and the certification of an evaporative loss factor for the item tested shall be conducted in accordance with the API *Manual of Petroleum Measurement Standards*, Chapter 19.3, Part F, "Evaporative Loss Factor for Storage Tanks Certification Program."

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Suggested revisions are invited and should be submitted to the standardization manager, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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0 Introduction

The purpose of this standard is to establish a uniform method for measuring evaporative deck-seam loss factors and deck-joint loss factors of mechanically-joined deck seams that are used on internal floating-roof tanks. These deck-seam loss factors and deck-joint loss factors are to be determined in terms of their loss rate at specified pressure differences across the deck seam or deck joint for certification purposes.

It is not the purpose of this standard to specify procedures to be used in the design, manufacture, or field installation of deck seams or deck joints. Furthermore, equipment should not be selected for use solely on the basis of evaporative-loss considerations. Many other factors, such as tank operation, maintenance, and safety, are important in designing and selecting tank equipment for a given application.

1 Scope

This test method may be used to establish evaporative deck-seam loss factors and deck-joint loss factors for mechanically-joined deck seams that are used on internal floating-roof tanks. The test method involves passing a controlled flow rate of air through a test enclosure that is sealed to the top deck of a test pan. The test pan incorporates the test deck seam or test deck joint and contains a test liquid. The total hydrocarbon concentration in the air streams entering and leaving the test enclosure are measured over a range of pressure differences across the test deck seam.

This standard specifies the test apparatus, the instruments, the test procedure, and the calculation procedures to be used. The variables that are to be measured are defined, and quality provisions are stipulated. The format for reporting the values of both the test results and their associated uncertainty are also specified.

This standard may involve the use of hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.

2 References

The following standards contain provisions which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

2.1 API REFERENCES

Manual of Petroleum Measurement Standards:

Chapter 15	"Guidelines for the Use of the International System of Units (SI) in the Petroleum and Allied Industries," Second Edition, December 1980.
Chapter 19.2	"Evaporative Loss From Floating Roof Tanks," First Edition, April 1997.
Chapter 19.3, Part F	"Evaporative Loss Factor for Storage Tanks Certification Program," First Edition, May 1997.
Chapter 19.3, Part G	"Certified Loss Factor Testing Laboratory Registration," First Edition, March 1997.
Chapter 19.3, Part H	"Tank Seals and Fittings Certification Administration," First Edition, March 1998.

Standards and Publications:

Standard 650	*Welded Steel Tanks for Oil Storage*, Tenth Edition, November 1998.

2.2 ASTM[1] REFERENCES

Standards:

D323	*Test Method for Vapor Pressure of Petroleum Products (Reid Method).*
D3195	*Standard Practice for Rotameter Calibration.*
E220	*Method for Calibration of Thermocouples by Comparison Techniques.*
E230	*Temperature—Electromotive Force (EMF) Tables for Standardized Thermocouples.*

[1]ASTM International, 100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428.

3 Terminology

3.1 DEFINITIONS

3.1.1 Covered Floating Roof

A floating roof that results from covering an external floating roof with a fixed roof at the top of the tank shell. This effectively converts the external floating roof to an internal floating roof, while retaining the external-type of floating-roof design. These floating roofs are typically designed in accordance with Appendix C of the API Standard 650, *Welded Steel Tanks for Oil Storage*.

3.1.2 Data Acquisition System (DAS)

The equipment used and process of receiving signals from sensors, determining the values corresponding to the signals, and recording the results.

3.1.3 Deck

That part of a floating roof that provides buoyancy and structure, and which covers the majority of the liquid surface in a bulk liquid storage tank. The deck has an annular space around its perimeter to allow it to rise and descend (as the tank is filled and emptied) without binding against the tank shell. This annular space is closed by a flexible device called a rim seal. The deck may also have penetrations, closed by deck fittings, that accommodate some functional or operational feature of the tank.

3.1.4 Deck Fitting

The device that substantially closes a penetration in the deck of a floating roof in a bulk liquid storage tank. Such penetrations are typically for the purpose of accommodating some functional or operational feature of the tank.

3.1.5 Deck Seam

The construction feature of a floating roof pertaining to the joint between adjacent deck sheets or deck panels. Certain types of internal floating roofs are constructed of deck sheets or deck panels that are joined by mechanical means at deck seams. Such mechanically-joined deck seams have an associated deck seam loss. Other types of internal or external floating roofs are constructed of metal sheets that are joined by welding. Such deck seams do not have an associated deck seam loss.

3.1.6 Deck Joint

The construction feature of a floating roof pertaining to the intersection of one deck seam with another deck seam or pertaining to the intersection of a deck seam with the rim of the floating roof. Mechanically-joined deck seams typically incorporate deck joints at locations where the deck seams intersect each other or intersect the rim of the floating roof. These deck joint locations have an associated deck joint loss that is separate from the deck seam loss.

3.1.7 Evaporative Loss Factor

An expression used to describe the evaporative loss rate characteristics of a given floating-roof device. In order to obtain the standing storage evaporative loss rate for a bulk liquid storage tank equipped with a floating roof, the evaporative loss factor for each evaporative loss contributing device is modified by certain characteristics of both the climatic conditions and the stored liquid. The characteristics of the stored liquid are expressed as a vapor pressure function, a vapor molecular weight, and a product factor.

3.1.8 External Floating Roof

A floating roof that is exposed to ambient environmental conditions by virtue of being in a bulk liquid storage tank that does not have a fixed roof at the top of the tank shell. External floating roofs are thus distinguished from internal floating roofs, which are located in tanks that do have a fixed roof to protect the floating roof from environmental exposure. External floating roofs are typically designed in accordance with Appendix C of the API Standard 650, *Welded Steel Tanks for Oil Storage*.

3.1.9 FET Facility

The entire facility used in the fugitive emission test (FET) method. The FET facility includes: the test pan; the test enclosure; the pressure and temperature sensors; the data acquisition system; the sample and dilution air pumps; the total hydrocarbon analyzers; the flow meters; and the associated flow tubing.

3.1.10 Floating Roof

A device that floats on the surface of the stored liquid in a bulk liquid storage tank. A floating roof substantially covers the liquid product surface, thereby reducing its potential for exposure to evaporation. Floating roofs are comprised of a deck, a rim seal, and miscellaneous deck fittings.

3.1.11 Fugitive Emission Test Method

The test method used to establish evaporative deck-seam loss factors and deck-joint loss factors for mechanically-joined deck seams that are used on internal floating-roof tanks. The fugitive emission test (FET) method involves passing a controlled flow rate of air through a test enclosure that is sealed to the top deck of a test pan over a test deck seam or over a test deck joint. The test pan contains a volatile hydrocarbon test liquid. The total hydrocarbon concentration in the air that enters and in the air that leaves the test enclosure is measured, along with the flow rate of the air leaving the test enclosure, at specified pressure differences across the test deck seam or test deck joint.

3.1.12 Indicator

An instrument that displays or records signals received from a sensor. The indicator is typically constructed to express the signal in units that are useful to describe the observed value of measurement. For example, an electronic signal may be received by the indicator as volts, but then displayed as pounds. An indicator may be incorporated into an electronic data acquisition system. An electronic data acquisition system typically has the capability to be pre-programmed to record data at prescribed time intervals, to analyze the data that has been received, and to electronically store the results.

3.1.13 Instrument

A device used in the measurement process to sense, transmit, or record observations.

3.1.14 Internal Floating Roof

A floating roof that is not exposed to ambient environmental conditions by virtue of being in a bulk liquid storage tank that has a fixed roof at the top of the tank shell. Internal floating roofs are thus distinguished from external floating roofs by their use of a fixed roof to protect the internal floating roof from environmental exposure. Internal floating roofs are typically designed in accordance with Appendix H of the API Standard 650, *Welded Steel Tanks for Oil Storage*.

3.1.15 Product Factor

A factor that describes the evaporative loss characteristics of a given liquid product. The product factor, vapor pressure function, and vapor molecular weight are multiplied by the sum of the equipment loss factors to determine the standing storage evaporative loss rate of a bulk liquid storage tank equipped with a floating roof.

3.1.16 Rim Seal

A flexible device that spans the annular rim space between the tank shell and the perimeter of the floating roof deck. Effective rim seals close the annular rim space, accommodate irregularities between the floating roof and the tank shell, and help to center the floating roof, yet permit normal floating roof movement.

3.1.17 Sensor

An instrument that senses attribute or measurement information that is to be obtained in a measurement process. This information is then transmitted to the indicator to be displayed or recorded.

3.1.18 Standing Storage Evaporative Loss

Loss of stored liquid product by evaporation past the floating roof during normal service conditions. This does not include evaporation of liquid that clings to the tank shell and is exposed to evaporation when the tank is being emptied (withdrawal loss); nor does it include vapor loss that may occur when the liquid level is sufficiently low so as to allow the floating roof to rest on its supports (landing loss). This does include, however, evaporative losses from the rim seal, deck seams, and deck fittings.

3.1.19 Test Enclosure

The portion of the FET facility that covers the test deck seam or test deck joint and is sealed to the top deck of the test pan.

3.1.20 Vapor Pressure Function

A dimensionless factor, used in the loss estimation procedure, that is a function of the ratio of the vapor pressure of the stored liquid to the average atmospheric pressure at the storage location. The vapor pressure function, the product vapor molecular weight, and the product factor are multiplied by the sum of the loss factors of the individual floating roof devices to determine the total standing storage evaporative loss rate of a bulk liquid storage tank equipped with a floating roof.

3.2 UNITS OF MEASUREMENT

3.2.1 System of Units

This standard employs the inch-pound units of the English system. Values shall be referenced to the U.S. National Institute of Standards and Technology (NIST) values (formerly the U.S. National Bureau of Standards). The text of this standard does not include equivalent International System of Units (SI) values, which is the system adopted by the International Organization of Standardization (ISO), but guidance for conversion to SI and other metric units is provided in Appendix B, Metric Units, and API *Manual of Petroleum Measurement Standards* Chapter 15.

3.2.2 Basic Units

The unit of length is either the mile, designated mi; the foot, designated ft; or the inch, designated in. The unit of mass is the pound mass, designated pound or lb. The unit of force is the pound force, designated pound-force or lbf. The unit of time is either the hour, designated hr, or the year, designated yr. The unit of temperature is the degree Fahrenheit, designated °F, or the degree Rankine, designated °R.

3.2.3 Pressure

The unit of pressure is the pound-force per square inch absolute, designated psia.

3.2.4 Deck-Seam Loss Factors

The unit of reporting deck-seam loss factors is the pound-mole per foot of deck seam per year, designated lb-mole/ft yr.

The units of the deck-seam loss factor, K_d, do not actually indicate pound-moles of vapor loss over time, but rather are units of a factor that must be multiplied by certain coefficients (which are dimensionless) in order to determine the actual pound-moles of evaporative loss over time for a given liquid product. To convert the pound-mole per foot of deck seam per year units of the deck-seam loss factor to a loss rate in terms of actual pound-moles per foot of deck seam per year, the deck-seam loss factor, K_d, is multiplied by the dimensionless vapor pressure function, $P*$, which is a function of the product vapor pressure and atmospheric pressure, and by the dimensionless product factor, K_c.

A pound-mole, designated lb-mole, is an amount of a substance the mass of which, when expressed in pounds, is equal to the numerical value of the molecular weight of the substance.

To then convert the actual pound-moles per foot of deck seam per year to pounds per year of a given liquid product, the loss rate (K_d $P*$ K_c) is multiplied by the total length of deck seam, L_d, having units of feet, and by the molecular weight of the liquid product in its vapor phase, M_v, having units of pounds per pound-mole. Additional information on this formula may be found in the API *Manual of Petroleum Measurement Standards*, Chapter 19.2.

3.2.5 Deck-Joint Loss Factors

The unit of reporting deck-joint loss factors is the pound-mole per year per deck joint, designated lb-mole/yr.

The units of the deck-joint loss factor, K_j, do not actually indicate pound-moles of vapor loss over time, but rather are units of a factor that must be multiplied by certain coefficients (which are dimensionless) in order to determine the actual pound-moles of evaporative loss over time for a given liquid product. To convert the pound-moles per deck joint per year units of the deck-joint loss factor to a loss rate in terms of actual pound-moles per deck joint per year, the deck-joint loss factor, K_j, is multiplied by the dimensionless vapor pressure function, $P*$, which is a function of the product vapor pressure and atmospheric pressure, and by the dimensionless product factor, K_c.

To then convert the actual pound-moles per year per deck joint to pounds per year of a given liquid product, the loss rate (K_j $P*$ K_c) is multiplied by the dimensionless total number of floating roof deck joints, N_j, and by the molecular weight of the liquid product in its vapor phase, M_v, the molecular weight having units of pounds per pound-mole. Additional information on this formula may be found in the API *Manual of Petroleum Measurement Standards*, Chapter 19.2.

3.3 NOMENCLATURE

Symbol	Description
A_p	Constant in the vapor pressure equation, dimensionless.
B_p	Constant in the vapor pressure equation, °R.
C_i	Concentration of hydrocarbon vapor in the test enclosure inlet air, ppmv.
C_o	Concentration of hydrocarbon vapor in the test enclosure outlet air, ppmv.
D	Tank diameter, ft.
D_s	Density of hydrocarbon vapor in the test enclosure outlet air at standard conditions, lb/sft^3.
E	Test enclosure loss rate, lb/min.
F	Test enclosure loss factor, lb-mole/yr.
K_c	Product factor of the test liquid, dimensionless.
K_d	Deck-seam loss factor, lb-mole/ft yr.
K_j	Deck-joint loss factor, lb-mole/yr.
L_d	Length of test deck seam, ft.
M_v	Molecular weight of the test liquid vapor, lb/lb-mole.
N_j	Total number of deck joints on the floating roof deck, dimensionless.
P	Vapor pressure of the test liquid, psia.
P_a	Atmospheric pressure, psia.
P_d	Pressure difference between the pressure inside the test pan vapor space and the inside the test enclosure, in wc.
P_s	Standard pressure (14.696), psia.
$P*$	Vapor pressure function, dimensionless.
Q_s	Volumetric flow rate of the test enclosure outlet air at standard conditions, sft^3/min.

R Universal gas constant (10.731), ft^3 psia/lb-mole °R.

RVP Reid vapor pressure of the test liquid, psi.

S Slope of the test liquid ASTM-D86 distillation curve at 10 volume percent evaporated, °F/volume %.

T_l Temperature of the test liquid, °F or °R.

T_s Standard temperature (60°F or 519.67°R), °F or °R.

4 Summary of Test Method

The test method described in this standard uses a mass balance procedure to measure a rate of evaporative loss through a test deck seam or a test deck joint. A test pan is fitted with a test deck seam that may include a test deck joint. A test enclosure is placed over the test deck seam and is sealed to the top deck of the test pan. The test pan is filled to an appropriate height with a volatile hydrocarbon test liquid of known properties, such as normal-hexane or iso-hexane. A measured flow rate of air is passed through the test enclosure and is controlled to maintain prescribed levels of pressure difference between the pressure in the test pan vapor space and the pressure in the test enclosure. The total hydrocarbon concentration in the air entering the test enclosure and in the air leaving the test enclosure are continuously measured using total hydrocarbon analyzers. A mass balance of the total hydrocarbon vapor in the air entering and in the air leaving the test enclosure is then made to determine the evaporative loss rate of hydrocarbon vapors through the test deck seam or test deck joint. The test enclosure loss rate is then factored for certain properties of the test liquid and the length of the test deck seam to determine an evaporative deck-seam loss factor or deck-joint loss factor.

5 Significance and Use

This test method establishes a procedure for measuring the evaporative deck-seam loss factor or deck-joint loss factor of mechanically joined deck seams that are used on internal floating-roof tanks. The testing is to be performed in a laboratory that has been approved by the API for this purpose, in accordance with the API *Manual of Petroleum Measurement Standards*, Chapter 19.3, Part G, "Certified Loss Factor Testing Laboratory Registration." The values determined by this method are to be evaluated in accordance with the API *Manual of Petroleum Measurement Standards*, Chapter 19.3, Part F, "Evaporative Loss Factor for Storage Tanks Certification Program," in order to assign API-certified loss factors to the particular deck seam or deck joint tested. The laboratory approval procedure, the test method, and the evaluation method together constitute a procedure by which manufacturers of floating-roof deck seams or floating-roof deck joints may obtain API-certified loss factors for deck seams or deck joints of their proprietary design.

6 Limitations To Test Method

6.1 EVALUATION OF RESULTS

The results of this test method are not intended to be used apart from their evaluation in accordance with the API *Manual of Petroleum Measurement Standards*, Chapter 19.3, Part F, "Evaporative Loss Factor for Storage Tanks Certification Program."

6.2 LOW LOSS RATES

This test method is not valid for deck seams or deck joints that have a loss rate lower than the specified tolerance of the instruments.

If it is determined that the loss rate of the test deck seam or test deck joint is less than the detection limit of the instrumentation, the report of test results shall state the de minimus value for the deck-seam loss factor or deck-joint loss factor that is based on the instrumentation detection limit.

7 Test Apparatus

7.1 TEST APPARATUS ILLUSTRATIONS

Figures 1, 2, and 3 are illustrations of the test apparatus that is to be used to obtain the measurements necessary for establishing a certified evaporative deck-seam loss factor or deck-joint loss factor for a mechanically-joined deck seam or deck joint that is used on an internal floating roof. Figure 1 is a flow diagram of the test apparatus that illustrates the test equipment and instrumentation. Figure 2 is a plan view of the fugitive emission test facility that illustrates the placement of the test equipment in the test room. Figure 3 is a view of the test assembly that illustrates the placement of the test enclosure over the test deck seam on the test pan.

7.2 TEST ROOM

The test room is to be large enough to house the test equipment, instrumentation, and personnel required for the test method. The test room shall be constructed and controlled such that the air temperature in the test room is capable of being maintained within ±5°F of a selected test room temperature for the duration of the test period.

7.2.1 Insulation

The test room should be insulated to aid in the control of the air temperature within the test room.

7.2.2 Air Temperature Control System

The test room shall have a dedicated temperature control system for maintaining the air temperature within the test room. The test room may also have a dedicated heater and air conditioner.

7.2.3 Circulation Fan

The test room shall be equipped with a fan that circulates the air within the test room to reduce air temperature variations in the test room.

7.2.4 Test Enclosure Inlet Air

The air that is directed into the test enclosure may be drawn from the air inside of the test room.

7.2.5 Access Doors

The test room shall be equipped with an equipment access door that is large enough to permit installation or removal of a test assembly. The test room may also be equipped with a smaller personnel access door to provide access to the instrumentation and data acquisition system, as well as to permit inspection of the test assembly during the test period.

7.3 TEST ASSEMBLY

Figure 3 illustrates a test assembly, which consists of a test pan, test deck seam or test deck joint, test enclosure, and test liquid.

7.3.1 Test Pan

The test pan is of rectangular shape and incorporates a top deck that simulates the deck of an internal floating roof. The test pan incorporates a fill connection and a drain connection for use in filling or draining test liquid from the test pan. The test pan shall be long enough to permit installation of a test deck seam that is a minimum of 10 feet long.

The test pan may incorporate multiple test deck seams. When multiple test deck seams are installed on the top deck of the test pan, there shall be a minimum spacing of at least 1 foot between the centers of adjacent test deck seams. There shall also be a minimum spacing of 1 foot from the longitudinal edge of the test pan to the adjacent test deck seam.

The test pan shall be equipped with a vent connection that permits the test pan vapor space above the test liquid to operate at near atmospheric pressure. The vent connection may be connected to a vent pipe that extends outside of the test room.

The test pan shall be equipped with a thermocouple that permits measuring the temperature of the test liquid during the test period.

The test pan may rest on any suitable surface, but its position shall be adjusted to insure that the level of the test liquid is essentially the same throughout the test pan relative to the position of the test deck seams or test deck joints. When testing deck seams or deck joints that normally contact the liquid product in a floating roof tank, the level of the test liquid and the position of the test pan shall be adjusted to insure that all portions of the test deck seam or test deck joint contact the test liquid in the same manner as occurs in normal service.

7.3.2 Test Deck Seam

To measure the deck-seam loss factor of a specific type of deck seam, the deck seam to be tested shall be mounted on the top deck of the test pan using the assembly and installation procedures that are normally used for the deck seam, as specified by the deck seam manufacturer. The only exception to the use of normal installation procedures involves the end joints where the test deck seam intersects the ends of the test pan, If these end joints are not contained within the test enclosure, their construction may be selected to facilitate installation of the test deck seam on the top deck of the test pan.

The surfaces of the test deck seam shall be clean and free of oil or other materials that may affect the deck-seam loss factor test results.

7.3.3 Test Deck Joint

To measure the deck-joint loss factor of a specific type of deck joint, the deck joint to be tested shall be mounted on the top surface of the test pan using the assembly and installation procedures that are normally used for the deck joint, as specified by the deck joint manufacturer. The test deck joints shall be incorporated into the portion of the deck seam that is contained within the test enclosure.

A specific test deck seam may incorporate multiple test deck joints. When multiple deck joins are incorporated into a test deck seam, there shall be a minimum spacing of at least 1 foot between the centers of adjacent test deck joints.

The surfaces of the test deck joint shall be clean and free of oil or other materials that may affect the deck-joint loss factor test results.

7.3.4 Test Enclosure

A test enclosure shall be placed over the test deck seam and test deck joint, if a test deck joint is incorporated into the test deck seam.

The test enclosure shall be sealed to the top surface of the test pan deck, as well as to the portions of the test deck seam which penetrate the ends or side walls of the test enclosure. A caulk, such as silicone caulk, may be used to provide the required seal.

A leak-tightness test may be performed on the test enclosure to ensure that there are no leak paths around the perimeter of the test enclosure where it is sealed to the top surface of the test pan and to the portions of the test deck seam that penetrate the ends or side walls of the test enclosure. An example of such a leak-tightness test consists of applying a slight gas pressure to the interior of the test enclosure and applying a leak detection liquid (typically a soap-like liquid that will form bubbles at vapor leaks) to the sealed edges of the test enclosure. If no bubbles are detected, it can be assumed that no significant test enclosure leaks are present.

The test enclosure shall be equipped with an inlet connection at one end for admitting air into the test enclosure, and an outlet connection at the other end for withdrawing the air, now laden with hydrocarbon vapor from evaporative losses through the test deck seam or test deck joint.

During a test to measure a deck-seam loss factor or a deck-joint loss factor, the pressure inside of the test enclosure shall be kept at prescribed vacuum levels relative to the pressure in the vapor space of the test pan.

7.4 TEST LIQUID

The test liquid shall be maintained at a level relative to the test deck seam or test deck joint that corresponds to that which is typical of industry practice for the deck seam or deck joint being tested.

The test liquid shall be normal-hexane (n-hexane) or isohexane, technical grade or better. During a test, the temperature of the test liquid shall not be permitted to exceed its normal boiling point temperature. A sample of the test liquid shall be tested to determine its Reid vapor pressure in accordance with ASTM D323.

7.4.1 Test Liquid Quantity

The required quantity of test liquid may be reduced by floating it on top of water. The depth of the test liquid layer shall be sufficient to ensure that it completely covers the surface of the water for the duration of the test. The depth of the test liquid layer must also be sufficient to ensure that the change in vapor pressure of the test liquid as a result of evaporation of lighter hydrocarbon components does not cause the test liquid vapor pressure to decrease by more than 5 percent during the duration of the test, and that at least one of the test liquid thermocouple is located within 1 inch below the test liquid surface (see 10.3.1.1).

7.4.2 Test Liquid Level

Test deck seams and test deck joints that normally contact the liquid product in a floating-roof storage tank shall be tested under the same conditions. In these cases the height of the test liquid shall be adjusted so that it contacts the test deck seam or test deck joint in the same manner as occurs in normal service.

A method of indicating the liquid level in the test pan shall be provided to control the initial filling and for monitoring purposes during a test. The preferred method of indicating the liquid level is by means of a sight tube, or window, but other methods that do not result in any loss of test liquid or its vapors may also be used.

All liquid-level fittings on the test pan, as well as those used for filling and emptying the test pan, must be leak tight.

7.5 TEST APPARATUS AIR FLOW

Figure 1 is a flow diagram of the test apparatus that illustrates the instrumentation and flow lines that are used to control and sample the air flow through the test enclosure. The instrumentation is described in Section 10.

7.5.1 Air Sampling

The air entering and leaving the test enclosure shall be continuously sampled to measure the total hydrocarbon concentration present in the air samples. Figure 1 illustrates the use of an inlet sample pump and an outlet sample pump to withdraw the required air samples from the air stream that is entering and the air stream that is leaving the test enclosure and send the samples to the total hydrocarbon analyzers.

The inlet and outlet sample pumps shall be diaphragm type compressors, which compress the air streams without oil contamination.

7.5.2 Test Enclosure Pressure Control

The test procedure requires that the pressure difference across the test deck seam or test deck joint be controlled at prescribed levels between 0.0 and 0.1 inches of water column. These pressure differences require that the pressure inside of the test enclosure be a vacuum relative to the pressure in the vapor space of the test pan.

The outlet sample pump has the dual functions of creating the vacuum condition that is required inside the test enclosure for a prescribed pressure difference across the test deck seam or test deck joint, as well as sampling the air leaving the test enclosure. An outlet flow control valve and an outlet flow meter are used in conjunction with the outlet sample pump to control and measure the air flow rate leaving the test enclosure. To create a prescribed pressure difference, the outlet sample pump may need to withdraw a larger air flow rate than is required for sampling. In these cases the excess air withdrawn by the outlet sample pump may be vented outside of the test room.

7.5.3 Sample Dilution

For certain tests, the total hydrocarbon concentration in the air leaving the test enclosure may exceed the full-scale range of the outlet total hydrocarbon analyzer. A sample dilution system may be used to dilute the outlet air sample with a measured quantity of dilution air to bring the total hydrocar-

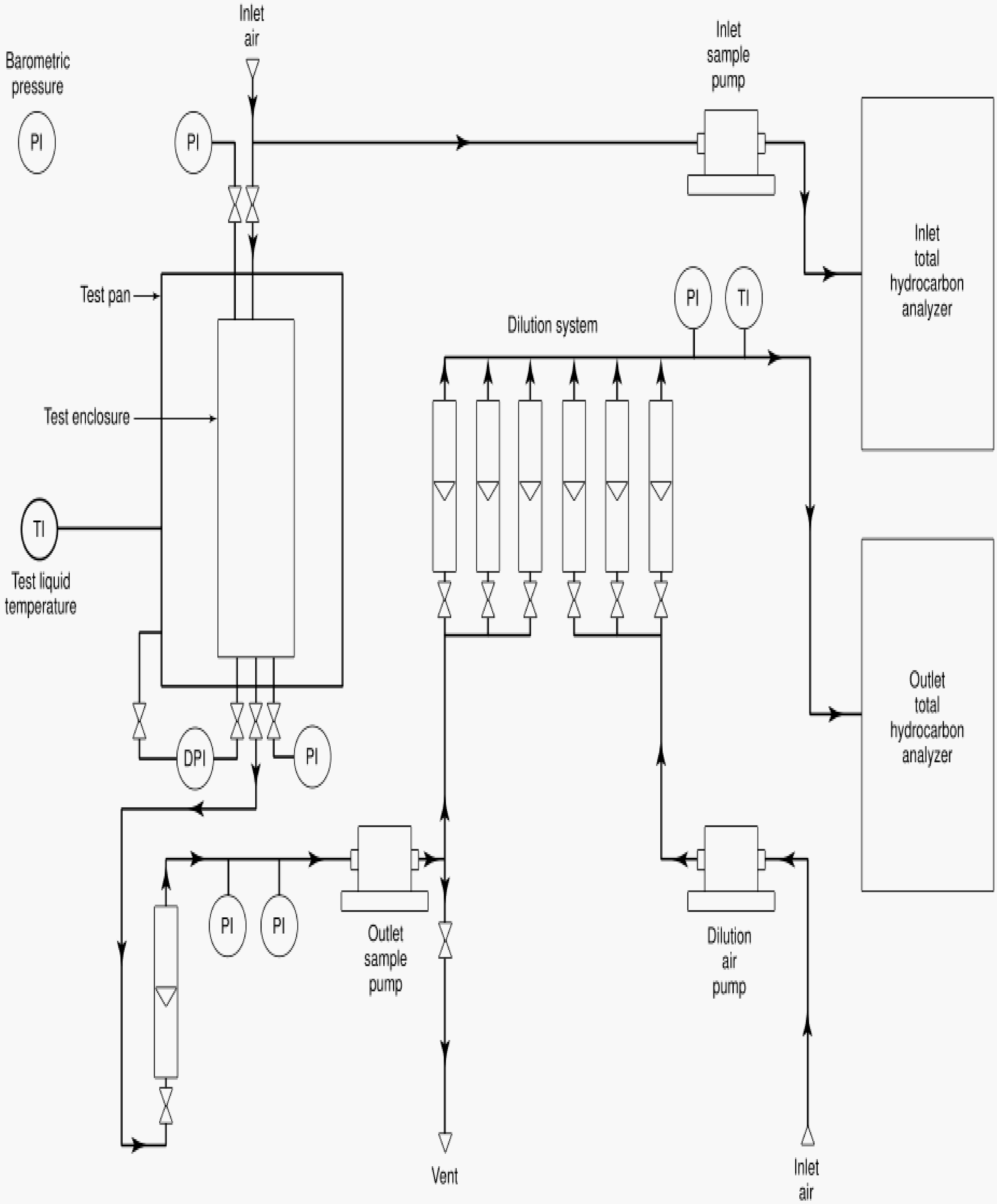


Figure 1—Flow Diagram of the Test Apparatus

bon concentration in the diluted outlet air sample within the full-scale range of the outlet total hydrocarbon analyzer.

Figure 1 illustrates one type of dilution system that may be used. This dilution system consists of a bank of rotameters to measure the flow rate of the outlet air sample from the test enclosure, and a second bank of rotameters to measure the flow rate of the dilution air. By selecting different pairs of outlet air rotameter and dilution air rotameter, the total hydrocarbon concentration in the diluted outlet air sample may be brought within the full-scale range of the outlet total hydrocarbon analyzer. The dilution air may be provided by a dilution air pump whose inlet air stream is taken from the air in the test room.

8 Test Item

8.1 TEST ITEM CONSTRUCTION

The items to be tested according to this test method are mechanically-joined deck seams or deck joints for internal floating-roof tanks. Items to be tested shall be full-scale samples. These shall be constructed according to the manufacturer's standard practice and shall include all features typical to actual use.

8.2 TEST ITEM ATTACHMENT

The deck seams or deck joints to be tested shall be attached to the top deck of the test pan in a manner similar to their attachment to the deck of an internal floating roof in practice. Test deck seams and test deck joints that normally contact the liquid product on a floating roof in service shall be mounted in a similar manner on the test pan.

8.3 TEST ITEM END CONNECTIONS

The ends of the test deck seam or test deck joint that intersect the end walls or side walls of the test enclosure shall be sealed to the walls of the test enclosure. A suitable sealant or caulk may be used for this purpose.

9 Preparation of Apparatus

9.1 TEST ITEM PLACEMENT

Install the test deck seam or test deck joint on the test pan, as described in 7.3.2, 7.3.3, and 8.2. Install the test enclosure over the test deck seam or test deck joint and seal it to the top deck of the test pan, as described in 7.3.4 and 8.3.

9.2 TEST LIQUID FILLING

Fill the test pan with the test liquid to the proper liquid level, as described in 7.4.

9.3 INSTRUMENTATION ATTACHMENT

Attach the instrumentation tubing to the test enclosure and test pan, as described in 7.5.

9.4 TEST ROOM AIR TEMPERATURE CONTROL

Start the test room air temperature control system to adjust the test room temperature to the selected value.

9.5 SAMPLE PUMP STARTUP

Start the inlet sample pump, outlet sample pump and dilution air pump to achieve the specified pressure difference between the pressure in the test pan vapor space and the pressure in the test enclosure, as prescribed in 11.1.

9.6 STEADY-STATE OPERATION

Start the data acquisition system and record the appropriate temperatures, pressures, and total hydrocarbon concentrations over a period of time until a steady evaporative loss rate is achieved. If the total hydrocarbon concentration in the outlet air sample exceeds the full-scale range of the outlet total hydrocarbon analyzer, adjust the amount of sample dilution, as described in 7.5.3.

After the initial startup period, during which the evaporation rate stabilizes, the subsequent test data recorded by the data acquisition system (as described in Section 11.2) shall constitute the record of test data that is to be used in calculating the deck-seam loss factor or deck-joint loss factor. The steady-state test period shall not be less than $^1/_2$ hour, as described in 11.3.

10 Instrumentation and Calibration

10.1 ACCURACY

Each parameter to be measured requires a sensor, an indicator, and a method of recording the data. The specifications that follow describe the required instruments, the methods to be employed in the measurement process, and the accuracy requirements. Calibration procedures are specified to minimize systematic error, or bias, in the instruments. The instrument requirements are summarized in Table 1.

Procedures are also specified for certain steps of the measurement process that have been identified as likely potential sources of random error, so as to limit the imprecision associated with these steps. One such step is the method of indicating observed values and recording them. The process of receiving signals from the sensors, determining the values corresponding to the signals, and recording the results may be collectively referred to as data acquisition. Data acquisition is to be accomplished with a programmable electronic data acquisition system, so that the frequency and precision of observations can be controlled within specified tolerances.

Table 1—Instrument Requirements

Variable to be Measured	Instrument Type	Maximum Tolerable Error	Maximum Calibration Interval
Time of the observation	Clock of the DAS	±0.1%	6 months
Temperature of the test liquid	Thermocouple	±0.5°F	6 months
Temperature of the air in the test room	Thermocouple	±0.5°F	6 months
Temperature of the air at flow rate sensors	Thermocouple	±0.5°F	6 months
Pressure of the air entering the test enclosure	Pressure sensor	±1%	6 months
Pressure of the air leaving the test enclosure	Pressure sensor	±1%	6 months
Pressure of the air leaving at the flow rate sensors	Pressure sensor	±1%	6 months
Atmospheric pressure in the test room	Pressure sensor	±0.05 psia	6 months
Pressure difference across the test deck seam	Pressure difference sensor	±1%	6 months
Flow rate of air leaving the test enclosure	Flow rate sensor	±1%	6 months
Flow rate of the undiluted outlet air sample	Flow rate sensor	±1%	6 months
Flow rate of the dilution air	Flow rate sensor	±1%	6 months
Total hydrocarbon concentration in the test enclosure inlet air	Total hydrocarbon analyzer	±1%	Every test
Total hydrocarbon concentration in the test enclosure outlet air	Total hydrocarbon analyzer	±1%	Every test

The demonstrated accuracy of the sensors shall be based on the readings indicated by the data acquisition system, thereby providing verification of the indicator as well as the sensor. Calibration standards shall be traceable to the national measurement reference standards maintained by NIST.

10.2 DATA ACQUISITION SYSTEM

The data acquisition system shall be capable of recording all of the data transmitted by the sensors. The data acquisition system shall include a chronometer that indicates time in intervals not greater than one second, with a demonstrated accuracy of ±0.1 percent. The data acquisition system shall be capable of being programmed to record individual sensor readings at a specified frequency. The data acquisition system should be capable of real-time display of the observed values, so that any out-of-specification conditions can be detected and corrected as soon as possible. The software of the system shall be verified by using the data acquisition system as the indicator when calibrating the sensors.

10.3 TEMPERATURE MEASUREMENTS

Temperatures shall be sensed with thermocouples and the signals transmitted to the data acquisition system. The temperature measuring system shall be capable of sensing temperature changes of ±0.2°F with a demonstrated accuracy of ±0.5°F.

10.3.1 Thermocouple Locations

Thermocouples shall be located so as to measure the bulk temperature of the test liquid, the temperature of the air in the test room and the temperature of the air passing through the test enclosure outlet air flow meter.

If the dilution system is used to dilute the test enclosure outlet air sample, a thermocouple shall also be located so as to measure the temperature of the air leaving the dilution system flow meters.

10.3.1.1 Test Liquid Temperature

At least one thermocouple shall be located within 1 inch below the test liquid surface in the test pan to measure the bulk temperature of the test liquid, as shown in Figure 3, so far as the water and test liquid temperature are identical (see 7.4.1).

10.3.1.2 Test Room Temperature

A thermocouple shall be located near the test assembly to measure the air temperature in the test room, as shown in Figure 1.

10.3.1.3 Test Enclosure Outlet Air Temperature

A thermocouple shall be located in the test enclosure outlet air line to measure the temperature of the air that is passing through the outlet air flow meter, as shown in Figure 1.

10.3.1.4 Dilution System Outlet Air Temperature

A thermocouple shall be located in the dilution system outlet air line to measure the temperature of the air leaving the dilution system flow meters, as shown in Figure 1.

10.3.2 Thermocouple Calibration

Each thermocouple shall be calibrated in accordance with ASTM E220 using the temperature measurement system. All thermocouple calibrations shall be based on the temperature-electromotive force tables that are listed in ASTM E230. The observed values shall not vary from the true values by more than ±0.5°F.

10.4 PRESSURE MEASUREMENTS

High-precision pressure sensors shall be used, where the indicated readings are gage pressure readings relative to the atmospheric pressure in the test room. If high-precision electronic pressure sensors are used, their output signal shall be recorded directly by the data acquisition system. The pressure being measured shall not exceed the sensor's measurable range, even during brief periods of pressure fluctuations.

10.4.1 Pressure Tap Locations

Pressure taps shall be located to measure the pressure of the air entering the test enclosure, the pressure of the air leaving the test enclosure, and the pressure of the air leaving the test enclosure outlet air flow meter, as shown in Figure 1.

If the dilution system is used to dilute the test enclosure outlet air sample, a pressure tap shall also be located so as to measure the pressure of the air leaving the dilution system flow meters, as shown in Figure 1.

10.4.2 Pressure Sensor Calibration

The pressure sensors shall be calibrated. The accuracy of electronic pressure sensors shall be based on the readings indicated by the data acquisition system.

The zero setting of the pressure sensors shall be checked and adjusted, if necessary, before each test.

10.5 ATMOSPHERIC PRESSURE MEASUREMENT

Atmospheric pressure shall be measured with an electronic pressure sensor and the signal transmitted to the data acquisition system. The atmospheric pressure sensor shall be capable of sensing atmospheric pressure changes of ±0.01 psia with a demonstrated accuracy of ±0.05 psia.

10.5.1 Atmospheric Pressure Sensor Location

The atmospheric pressure sensor shall be located near the data acquisition system to measure the atmospheric pressure in the test room, as shown in Figure 1.

10.5.2 Atmospheric Pressure Sensor Calibration

The atmospheric pressure sensor shall be calibrated for at least two levels of pressure using the atmospheric pressure measurement system. The observed values shall not vary from the true values by more than ±0.05 psia. The accuracy of the atmospheric pressure sensor shall be based on the readings indicated by the data acquisition system.

10.6 PRESSURE DIFFERENCE MEASUREMENT

A high-precision electronic pressure difference sensor shall be used to measure the pressure difference across the test deck seam or test deck joint, and the output signal shall be recorded directly by the data acquisition system. The measured pressure shall not exceed the sensor's measurable range, even during brief periods of pressure fluctuations.

10.6.1 Pressure Tap Locations

The high pressure side of the pressure difference sensor shall be connected to a pressure tap that senses the pressure in the test pan vapor space, and the low pressure side of the pressure difference sensor shall be connected to a pressure tap that senses the pressure in the test enclosure, as shown in Figure 1.

10.6.2 Pressure Difference Sensor Calibration

The pressure difference sensor shall be calibrated. The accuracy of the pressure difference sensor shall be based on the readings indicated by the data acquisition system.

The zero setting of the pressure difference sensor shall be checked and adjusted, if necessary, before each test.

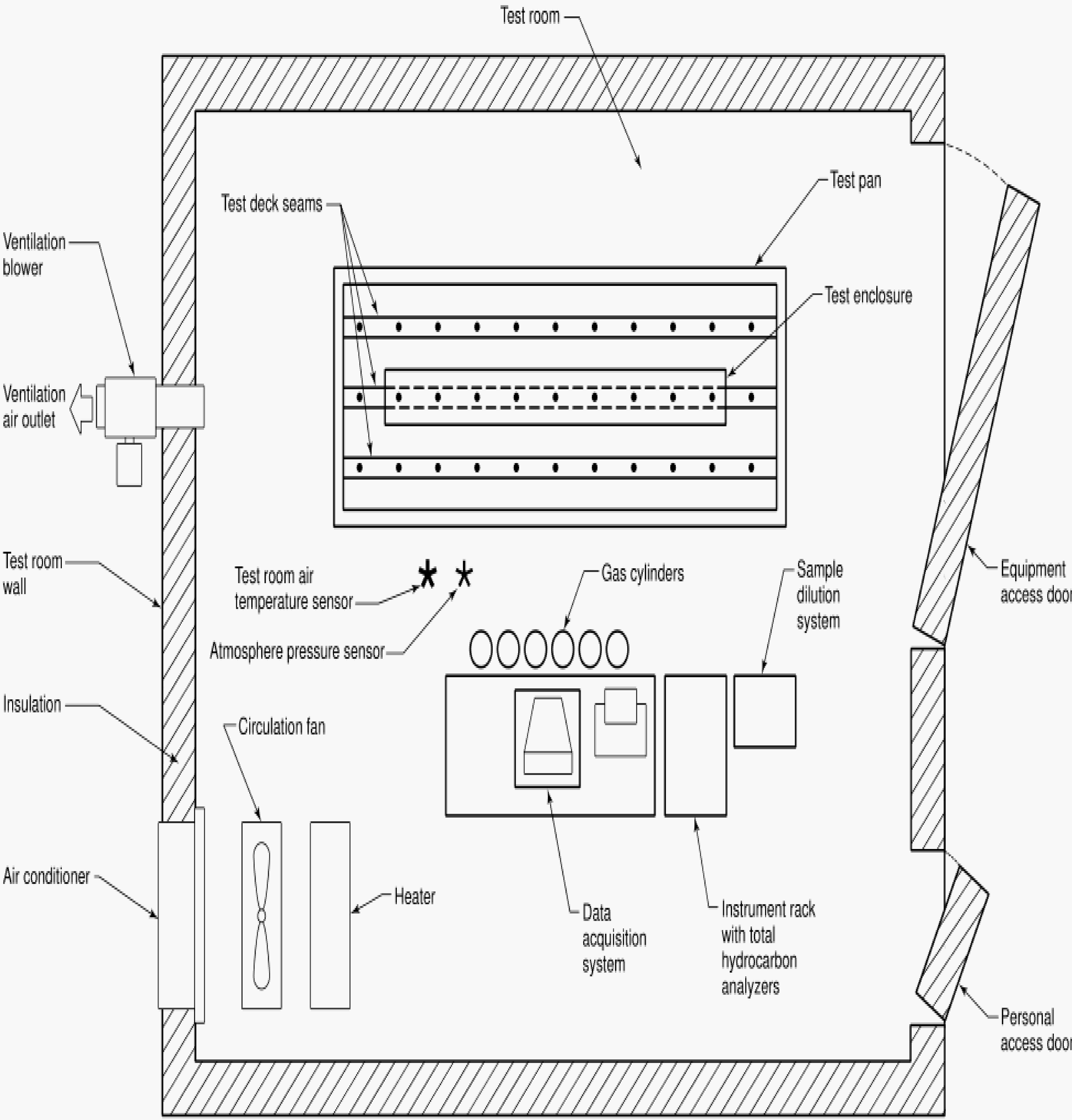


Figure 2—Plan View of the Fugitive Emission Test Facility

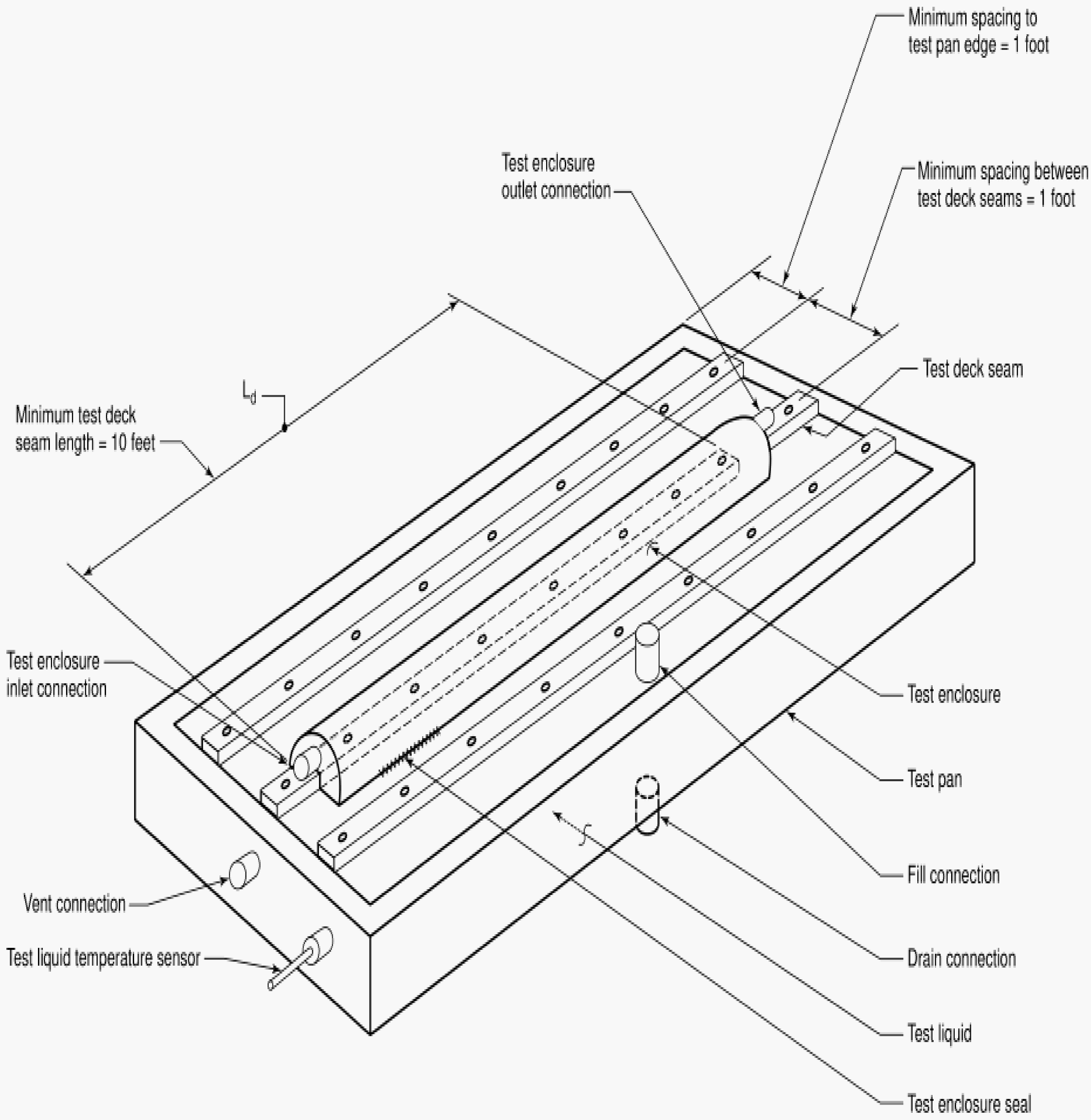


Figure 3—Test Assembly

10.7 FLOW RATE MEASUREMENTS

Flow rates shall be sensed with high-precision gas flow meters, such as high-precision gas rotameters. If high-precision electronic flow rate sensors are used, their output signal shall be recorded directly by the data acquisition system. The measured gas flow rates shall not be below 10 percent of the meter's or sensor's full-scale range.

10.7.1 Flow Meter Locations

A flow meter shall be located to measure the flow rate of the air leaving the test enclosure, as shown in Figure 1.

If the dilution system is used to dilute the test enclosure outlet air sample, the dilution system may incorporate several flow meters to measure the flow rates of the undiluted air sample stream and the flow rate of the dilution air stream, as shown in Figure 1. The flow rate measurement of the undiluted outlet air sample stream and the flow rate of the dilution air stream are used to relate the total hydrocarbon concentration measurements in the diluted outlet air sample stream to those in the undiluted outlet air sample stream.

10.7.2 Flow Meter Calibration

The flow meters shall be calibrated. Rotameters shall be calibrated in accordance with ASTM D3195, *Standard Practice for Rotameter Calibration*. The accuracy of electronic flow rate sensors shall be based on the readings indicated by the data acquisition system.

10.8 TOTAL HYDROCARBON CONCENTRATION MEASUREMENTS

The total hydrocarbon concentration in the test enclosure inlet air line and outlet air line shall each be measured with a total hydrocarbon analyzer (THA) or equivalent instrument. The electronic output signal from the THAs shall be recorded directly by the data acquisition system.

If the total hydrocarbon concentration in the outlet air sample exceeds the full-scale range of the outlet THA, a sample dilution system may be used. The sample dilution system shall incorporate a means for measuring the flow rate of the undiluted outlet air sample stream and the flow rate of the dilution air stream. Rotameters may be used to provide these gas flow rate measurements.

10.8.1 Sample Tap Locations

Sample taps shall be located to sample the test enclosure inlet air stream and to sample the test enclosure outlet air stream, as described in Figure 1.

10.8.2 Analyzer Calibration

The THA instruments shall be calibrated during a test at intervals not exceeding 12 hours using zero and span gases of known certified composition.

11 Test Procedure

11.1 LEVELS OF PRESSURE DIFFERENCE

Tests shall be conducted at pressure differences of approximately 0.02, 0.04, 0.06, 0.08, and 0.10 inches of water column for each deck seam and deck joint that is tested. These pressure differences are between the pressure in the test pan vapor space and the pressure in the test enclosure, where the pressure in the test enclosure is kept less than the pressure in the test pan vapor space.

Tests at additional pressure differences may also be performed and can sometimes help in determining the pressure difference dependency of the deck-seam loss factor or deck-fitting loss factor.

11.2 DATA TO BE RECORDED

11.2.1 Test Item Description

A description of the test deck seam or test deck joint shall be recorded, including the name of the manufacturer and any model name or number. Dimensions of the test deck seam or test deck joint shall be recorded on a drawing. Photographs shall be taken to document the test deck seam or test deck joint, its installation procedure, and its final arrangement on the top deck of the test pan.

11.2.2 Instruments

Names, model numbers, serial numbers, scale ranges, and calibration data shall be recorded for all instruments used in the test.

11.2.3 Test Data

Test data for each loss factor determination shall be recorded. Test data shall be recorded electronically by the data acquisition system to a storage device from which it may be downloaded to a printer. All recorded data shall include the time of the observed reading. Each of the following test data shall be recorded during the steady-state test period.

11.2.3.1 Temperatures

The temperature of the test liquid, the temperature of the air in the test room, and the temperature of the air at flow meters shall be recorded at intervals of 10 minutes or less.

11.2.3.2 Pressures

The pressure in the test pan vapor space, the pressure in the test enclosure, and the pressure at flow meters shall be recorded at intervals of 10 minutes or less.

11.2.3.3 Atmospheric Pressure

The atmospheric pressure in the test room shall be recorded at intervals of 10 minutes or less.

11.2.3.4 Pressure Difference

The pressure difference between the pressure in the test pan vapor space and the pressure in the test enclosure shall be recorded at intervals of 10 minutes or less.

11.2.3.5 Flow Rates

The air flow rate leaving the test enclosure shall be recorded at intervals of 10 minutes or less.

If a dilution system is used to dilute the test enclosure outlet air sample, the flow rate of the undiluted outlet air sample stream and the flow rate of the dilution air stream shall be recorded at intervals of 10 minutes or less.

11.2.3.6 Total Hydrocarbon Concentrations

The total hydrocarbon concentration in the air entering and in the air leaving the test enclosure shall be recorded at intervals of 10 minutes or less.

11.2.3.7 Test Liquid Reid Vapor Pressure

The Reid vapor pressure of the test liquid shall be determined at least once for each test performed. The true vapor pressure of the test liquid shall be based on the Reid vapor pressure determined from a sample of the test liquid obtained during the test period or from an interpolated Reid vapor pressure based on the Reid vapor pressure determined from samples of the test liquid obtained both before and after the test period.

11.2.4 Log Book

An operator's log book shall be maintained to document any general observations, as well as the sequence and timing of the tests performed. In addition, the log book shall contain recorded data concerning the test pan liquid level.

11.3 DURATION OF TEST

The emission characteristics of a test deck seam or test deck joint may change after a change is made in the test conditions (for example, pressure difference across the test deck seam) as new emission flow paths are created and concentration gradients are established. As a result, sufficient time must be allowed to establish a steady-state evaporative loss rate. To test for steady evaporative loss rate conditions, trial observations may be made until steady readings are observed. Data shall then be recorded for a period of not less than $^1/_2$ hour after obtaining steady readings. In any event, a test shall not be considered steady until a minimum of $^1/_2$ hour has elapsed. Thus, the absolute minimum test duration would be 1 hour (that is, $^1/_2$ hour to establish steady conditions, then $^1/_2$ hour of steady-state data recording). Typical test duration's are apt to extend from 1 to 2 hours.

12 Calculation of Test Results

12.1 CALIBRATION CORRECTIONS

Calibration corrections shall be applied to individual readings before performing calculations. These corrections may be applied by the data acquisition system to individual readings during the course of the test.

12.2 VAPOR PRESSURE

The vapor pressure, *P*, of the test liquid shall be determined from the measured Reid vapor pressure, *RVP*, of the test liquid and the mean of the test liquid temperature, T_l, recorded during the steady-state test period.

The vapor pressure constants, A_p and B_p, of the test liquid may be calculated from the measured Reid vapor pressure, *RVP*, using Equations 1 and 2.

$$A_p = 15.64 - 1.854\, S^{0.5} - (0.8742 - 0.3280\, S^{0.5})\, ln\, RVP \quad (1)$$

$$B_p = 8742 - 1042\, S^{0.5} - (1049 - 179.4\, S^{0.5})\, ln\, RVP \quad (2)$$

where:

A_p = vapor pressure constant (dimensionless),

B_p = vapor pressure constant (°R),

RVP = test liquid Reid vapor pressure (psi),

S = test liquid ASTM-D86 distillation slope at 10 volume percent evaporated (°F/volume %), and

ln = natural logarithm function.

For a test liquid that is normal-hexane (n-hexane) or isohexane, technical grade or better, the test liquid distillation slope, *S*, may be assumed to be 0°F/volume %. Equations 1 and 2 then simplify to Equations 3 and 4.

$$A_p = 15.64 - 0.8742\, ln\, RVP \quad (3)$$

$$B_p = 8742 - 1049\, ln\, RVP \quad (4)$$

For pure n-hexane, the vapor pressure constants A_p and B_p are:

$$A_p = 13.824 \text{ (dimensionless), and} \quad (5)$$

$$B_p = 6{,}907.2\ (°R). \quad (6)$$

For iso-hexane, the vapor pressure constants A_p and B_p depend on the actual test liquid composition.

The vapor pressure of the test liquid shall be calculated from Equations 7 and 8.

$$(T_l, °R) = (T_l, °F) + 459.67 \quad (7)$$

$$P = \exp\,[A_p - (B_p\,/\,(T_l, °R))] \quad (8)$$

where:

P = vapor pressure of the test liquid (psia);

T_l = mean temperature of the test liquid (°F or °R); and

exp = exponential function.

12.3 VAPOR PRESSURE FUNCTION

The vapor pressure function, P^*, as described in the API *Manual of Petroleum Measurement Standards*, Chapter 19.2 shall be calculated from Equation 9.

$$P^* = (P\,/\,P_a)\,/\,[1 + (1 - (P\,/\,P_a))^{0.5}]^2 \quad (9)$$

where:

P_a = mean atmospheric pressure in the test room during the steady-state test period (psia).

12.4 VAPOR DENSITY

The density of the test liquid vapor at standard conditions shall be calculated from Equation 10.

$$D_s = P_s\,M_v\,/\,R\,(T_s, °R) \quad (10)$$

where:

D_s = density of the test liquid vapor at standard conditions (lb/sft^3),

P_s = standard pressure (14.696 psia),

T_s = standard temperature (519.67°R),

R = universal gas constant (10.731 ft^3 psia/lb-mole °R), and

M_v = molecular weight of the test liquid vapor (lb/lb-mole).

The molecular weight of the test liquid vapor, M_v, shall be based on a composition analysis of the test liquid.

12.5 TEST ENCLOSURE LOSS RATE

The test enclosure loss rate, E, at each pressure difference shall be calculated from Equation 11.

$$E = (1 \text{ volume fraction}/10^6 \text{ ppmv})\ Q_s\,D_s\,(C_o - C_i) \quad (11)$$

where:

E = test enclosure loss rate (lb/min),

Q_s = volumetric flow rate of test enclosure outlet air at standard conditions (sft^3/min),

C_i = concentration of hydrocarbon vapor in the test enclosure inlet air (ppmv), and

C_o = concentration of hydrocarbon vapor in the test enclosure outlet air (ppmv).

The test enclosure loss rate that is to be used in determining a deck-seam loss factor or a deck-joint loss factor shall be based on the mean of the test enclosure loss rates that are determined during the steady-state test periods.

12.6 TEST ENCLOSURE LOSS FACTOR

The test enclosure loss factor, F, at each pressure difference shall be calculated from Equation 12.

$$F = (60 \text{ min/hr})(24 \text{ hr/day})(365.25 \text{ days/yr})\ E\,/\,P^*\,M_v\,K_c \quad (12)$$

where:

F = test enclosure loss factor (lb-mole/yr),

M_v = molecular weight of the test liquid vapor (lb/lb-mole),

= 86.18 (lb/lb-mole) for n-hexane, and

K_c = product factor of the test liquid (dimensionless),

= 1.0 (dimensionless) for n-hexane and iso-hexane.

12.7 DECK-SEAM LOSS FACTOR

The deck-seam loss factor, K_d, at each pressure difference shall be calculated from Equation 13.

$$K_d = F / L_d \tag{13}$$

where:

K_d = deck-seam loss factor (lb-mole/ft yr), and

L_d = length of test deck seam (ft).

12.8 DECK-JOINT LOSS FACTOR

The deck-joint loss factor, K_j, at each pressure difference shall be calculated from Equation 14.

$$K_j = F - L_d\,K_d \tag{14}$$

where:

K_j = deck-joint loss factor (lb-mole/yr).

12.9 UNCERTAINTY ANALYSIS

Determine the uncertainty in the calculated deck-seam loss factor, K_d, or deck-joint loss factor, K_j, by using the procedure described in Appendix A, U*ncertainty Analysis*.

13 Report of Test Results

13.1 REPORT

The report of a laboratory test to determine the deck-seam loss factor or deck-joint loss factor of a test deck seam or test deck joint shall include:

a. Name and location of the testing laboratory.

b. Description and drawings of the test apparatus.

c. Name and location of the deck seam or deck joint manufacturer.

d. Reid vapor pressure of the test liquid, as required in 7.4.

e. Description and drawings of the test deck seam or test deck joint, as required in 11.2.1.

f. Description and calibration data for the instruments, as required in 11.2.2.

g. Test data, as required in 11.2.3.

h. Results of calculation, as required in 12.

i. Results of the uncertainty analysis, as outlined in Appendix A.

j. Results of the loss factor versus pressure difference correlation equation determination, as required in 13.3.2.

13.2 DATA CURVES

Each value of the test enclosure loss rate, E, shall be presented on a time-based loss rate curve, which shall include the individual test enclosure loss rate values from the beginning of the test through the steady-state test period. The values shown on the curve shall be the calculated test enclosure loss rate, E, values, as described in 12.5. A typical test enclosure loss rate curve is shown in Figure 4.

Accompanying curves and tables shall be included that show:

a. Air flow rate leaving the test enclosure, Q_s.

b. Pressure difference across the test deck seam or test deck joint, P_d.

c. Total hydrocarbon concentration in the air entering the test enclosure, C_i.

d. Total hydrocarbon concentration in the air leaving the test enclosure, C_o.

e. Temperatures of the test liquid, T_l, the air passing through flow meters, and the air in the test room.

f. Atmospheric pressure in the test room, P_a.

These curves shall include each of the individual values from the beginning of the test through the steady-state test period.

13.2.1 Coordinates

The data curves shall be drawn with time as the abscissa and the associated test parameter (for example, test enclosure loss rate, total hydrocarbon concentration in the test enclosure outlet air, and so forth) as the ordinate.

13.2.2 Display

Date curves shall show the individual readings. The mean value of each test parameter during the steady-state test period shall be listed along with its standard deviation and uncertainty based on a 95-percent confidence interval. Each data curve shall list the test number, the test deck seam or test deck joint description, the pressure difference across the test deck seam or the test deck joint, and the names of the manufacturer and the test laboratory.

13.3 LOSS FACTOR GRAPH

The results of all tests for a given test deck seam or test deck joint shall be presented on a loss factor graph. A typical deck-seam loss factor graph is shown in Figure 5.

13.3.1 Coordinates

Loss factor graphs shall be drawn with pressure difference as the abscissa and the deck-seam loss factor or deck-joint loss factor as the ordinate.

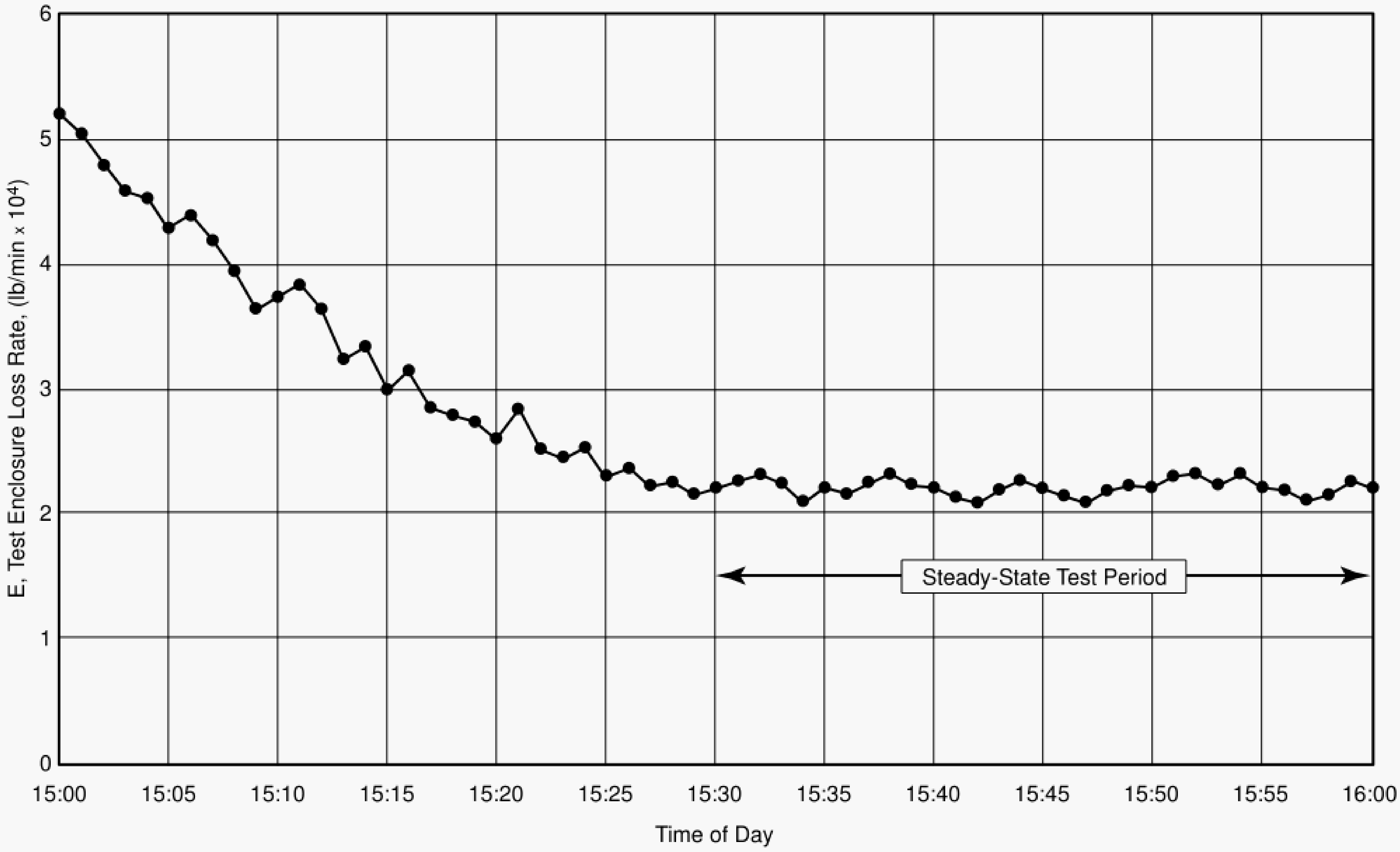
13.3.2 Display

The deck-seam loss factor or deck-joint loss factor that was determined for each test shall be shown as a point with its 95-percent confidence interval on the loss factor graph. In the event that a loss factor was obtained for more than one test at a specific level of pressure difference, the loss factor determined for each test shall be shown along with the mean loss factor for that level of pressure difference. The value of the loss factor and its 95-percent confidence interval shall be listed to three significant figures, either on the graph or on an accompanying table.

The curve of the loss factor versus pressure difference correlation shall also be displayed, along with the value of the loss factor that is predicted for a pressure difference of 0.05 inches of water column. The loss factor graph shall list the test deck seam or test deck joint description and the names of the manufacturer and test laboratory.

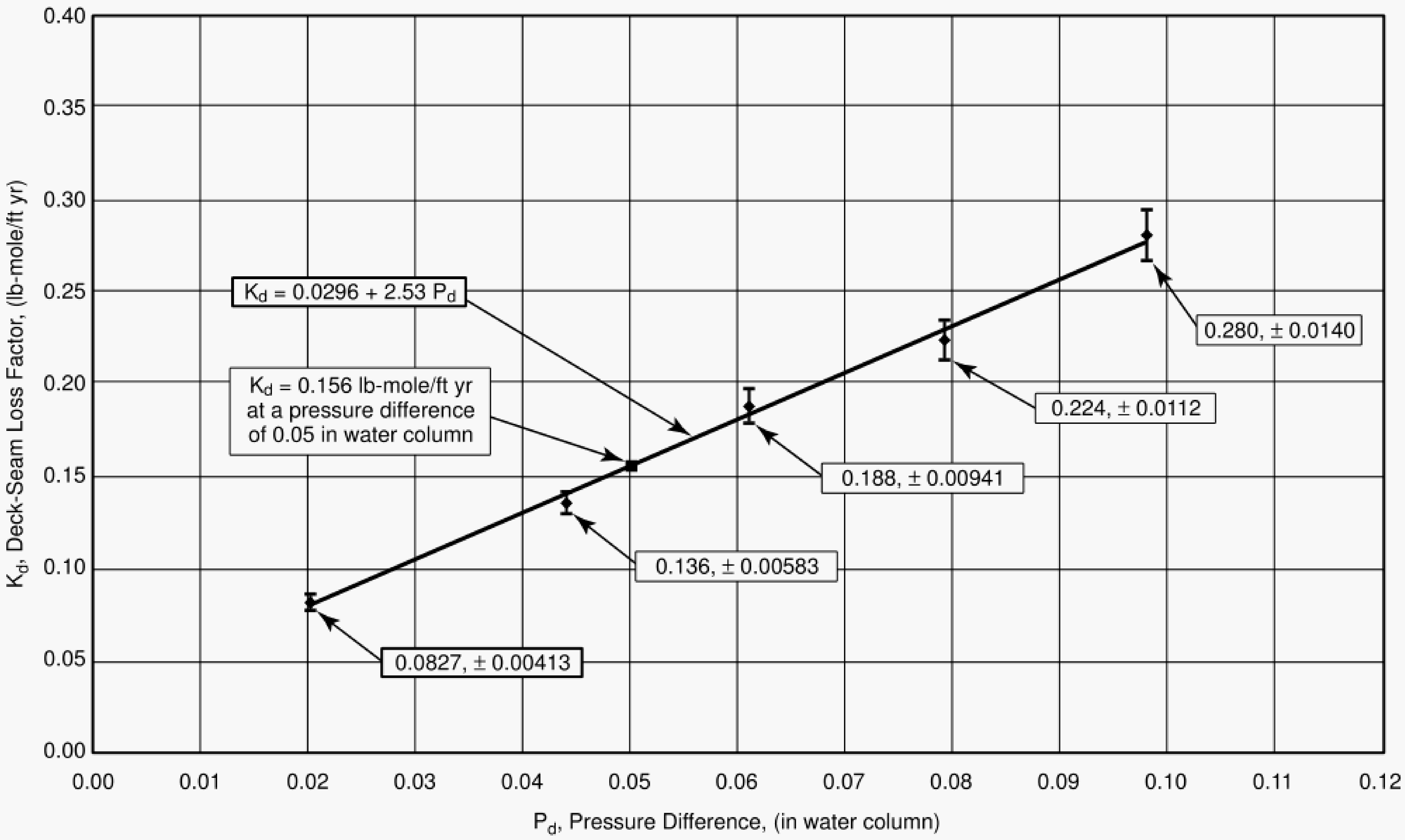
14 Precision and Bias

The uncertainty in a measured evaporative deck-seam loss factor or deck-joint loss factor indicates the probable or possible difference between the measured value and the true value. This uncertainty shall be obtained by using the procedure described in Appendix A, *Uncertainty Analysis*, which uses the uncertainties in the individual measurements that include the effects of random error (imprecision) and systematic error (bias).



Item	Value
• Test Deck Seam Description:	Non-Contact Deck Seam
• Pressure Difference:	0.0440, ±0.0020 in wc
• Mean Test Enclosure Loss Rate:	2.2085×10^{-5} lb/min
Standard Deviation:	3.6428% of the mean value
95% Confidence Interval:	+8.0449 x 10-7 lb/min
• Test Number:	1
• Deck Seam Manufacturer:	Deck-R-Us
• Test Laboratory:	Tests-R-Us

Figure 4—Typical Test Enclosure Loss Rate Curve



Item	Value
• Test Deck Seam Description:	Non-Contact Deck Seam
• Deck Seam Manufacturer:	Deck-R-Us
• Test Laboratory:	Tests-R-Us
• Deck-Seam Loss Factor versus pressure difference correlation:	$K_d = 0.0296 + 2.53\ P_d$
• Deck-Seam Loss Factor at a pressure difference of 0.05 in wc:	0.156 lb-mole/ft yr

Figure 5—Typical Deck-Seam Loss Factor Graph

APPENDIX A—UNCERTAINTY ANALYSIS

A.1 General

Loss factor determinations are always subject to some level of uncertainty as result of uncertainties in the measured variables. These individual uncertainties include both a systematic component, which is expressed as bias, and a random component, which is expressed as imprecision.

Appendix A describes a calculation method that shall be used to determine the uncertainty in the deck-seam loss factor, K_d, and the deck-joint loss factor, K_j, that results from the effects of the individual measurement uncertainties. The result of these calculations shall be included in the report of test results.

A.2 Definitions

The following definitions are used in Appendix A:

X = measured quantity,

U_x = absolute uncertainty in X,

E_x = per unit uncertainty in X.

From these definitions it follows that:

$$E_x = U_x / X \quad \text{(A-1)}$$

The per unit uncertainty, E_x, used in this standard shall be based on a 95-percent confidence limit, which implies that out of a large number of measurements having a normal statistical distribution, 95-percent may be expected to be within the limits specified, with 2.5 percent above the top limit and 2.5 percent below the bottom limit.

The results of measurements shall be reported as shown in Equation A-2.

$$X + U_x \quad \text{(A-2)}$$

A.3 Nomenclature

The nomenclature used in Appendix A consists of the nomenclature previously listed in 3.3, as well as that listed in the following table.

Symbol	Description
R_p	Ratio of vapor pressure to atmospheric pressure, dimensionless

Per Unit Uncertainty of:

E_{Ap}	Constant in the vapor pressure equation, dimensionless.
E_{Bp}	Constant in the vapor pressure equation, dimensionless.
E_{Ci}	Inlet concentration, dimensionless.
E_{Co}	Outlet concentration, dimensionless.
E_{Ds}	Density of the test liquid vapor at standard conditions, dimensionless.
E_E	Test enclosure loss rate, dimensionless.
E_F	Test enclosure loss factor, dimensionless.
E_{Kc}	Product factor, dimensionless.
E_{Kd}	Deck-seam loss factor, dimensionless.
E_{Kj}	Deck-joint loss factor, dimensionless.
E_{Ld}	Deck seam length, dimensionless.
E_{Mv}	Molecular weight of the test liquid vapor, dimensionless.
E_P	Vapor pressure of the test liquid, dimensionless.
E_{P*}	Vapor pressure function, dimensionless.
E_{Pa}	Atmospheric pressure, dimensionless.
E_{Pd}	Pressure difference across the deck seam, dimensionless.
E_{Qs}	Flow rate through the test enclosure, dimensionless.
E_{Rp}	Ratio of vapor pressure to atmospheric pressure, dimensionless.
E_{RVP}	Reid vapor pressure, dimensionless.
E_{Tl}	Temperature of the test liquid, dimensionless.

Absolute Uncertainty of:

U_{Ap}	Constant in the vapor pressure equation, dimensionless.
U_{Bp}	Constant in the vapor pressure equation, °R.
U_{Ci}	Inlet concentration, ppmv.
U_{Co}	Outlet concentration, ppmv.
U_{Ds}	Density of the test liquid vapor at standard conditions, lb/sft^3.
U_E	Test enclosure loss rate, lb/min.
U_F	Test enclosure loss factor, lb-mole/yr.

U_{Kc} Product factor, dimensionless.

U_{Kd} Deck-seam loss factor, lb-mole/ft yr.

U_{Kj} Deck-joint loss factor, lb-mole/yr.

U_{Ld} Deck seam length, ft.

U_{Mv} Molecular weight of test liquid vapor, lb/lb-mole.

U_P Vapor pressure of the test liquid, psia.

U_{P*} Vapor pressure function, dimensionless.

U_{Pa} Atmospheric pressure, psia.

U_{Pd} Pressure difference across the deck seam, in wc.

U_{Qs} Flow rate through the test enclosure, sft^3/min.

U_{Rp} Ratio of vapor pressure to atmospheric pressure, dimensionless.

U_{RVP} Reid vapor pressure, psi.

U_{Tl} Temperature of the test liquid, °F or °R.

A.4 Uncertainty Formulas

This section presents the formulas that shall be used to calculate the uncertainties.

A.4.1 UNCERTAINTY IN THE VAPOR PRESSURE CONSTANTS

The per unit uncertainty in the vapor pressure constants A_p and B_p shall be calculated from Equations A-3 and A-4, respectively.

$$E_{Ap} = (0.8742)\ E_{RVP}/A_p \qquad \text{(A-3)}$$

$$E_{Bp} = (1049)\ E_{RVP}/B_p \qquad \text{(A-4)}$$

A sample of the test liquid shall be tested to determine its Reid vapor pressure in accordance with ASTM D323. That test shall also include a value for the per unit uncertainty in the Reid vapor pressure, E_{RVP}.

A.4.2 UNCERTAINTY IN THE VAPOR PRESSURE

The per unit uncertainty in the vapor pressure, E_P, shall be calculated from Equation A-5.

$$E_P = [A_p^2 E_p^2 + (B_p/T_l)^2\ (E_{Bp}^2 + E_{Tl}^2)]^{0.5} \qquad \text{(A-5)}$$

The temperature of the test liquid, T_l, may vary during the course of a test. The test liquid vapor pressure, P, used in the loss factor determination shall be based on the mean of the measurements of the test liquid temperature recorded during the $^1/_2$ hour steady-state test period. The per unit uncertainty in the mean temperature of the test liquid shall include any known bias errors in the calibration of the temperature measurement instrumentation, as well as any random errors resulting from variations in the temperature of the test liquid during the steady-state test period.

A.4.3 UNCERTAINTY IN THE VAPOR PRESSURE FUNCTION

In determining the per unit uncertainty in the vapor pressure function, P^*, it is convenient to define the parameter R_p as the ratio of the stock vapor pressure, P, to atmospheric pressure, P_a, as shown in Equation A-6.

$$R_p = P\ /\ P_a \qquad \text{(A-6)}$$

The per unit uncertainty in R_p shall be calculated from Equation A-7.

$$E_{Rp} = [E_P^2 + E_{Pa}^2]^{0.5} \qquad \text{(A-7)}$$

The atmospheric pressure, P_a, may vary during the course of a test. The atmospheric pressure used in the loss factor determination shall be based on the mean of the measurements of atmospheric pressure recorded during the $^1/_2$ hour steady-state period. The per unit uncertainty in the mean atmospheric pressure shall include any known bias errors in the calibration of the atmospheric pressure measurement instrumentation, as well as random errors resulting from variations in the atmospheric pressure during the steady-state test period. Is should be noted, however, that the per unit uncertainty in the mean atmospheric pressure, E_{Pa}, is typically small in comparison to the per unit uncertainty in the mean stock vapor pressure, E_P.

The per unit uncertainty in the vapor pressure function, E_{P*}, shall be calculated from Equation A-8.

$$E_{P*} = [1/(1 - R_p)^{0.5}]\ E_{Rp} \qquad \text{(A-8)}$$

A.4.4 UNCERTAINTY IN THE VAPOR DENSITY

The per unit uncertainty in the density of the test liquid vapor at standard conditions, E_{Ds}, shall be calculated from Equation A-9.

$$E_{Ds} = E_{Mv} \qquad \text{(A-9)}$$

A sample of the test liquid shall be analyzed to determine its vapor molecular weight, M_v. That vapor molecular weight determination shall also include a value for the per unit uncertainty in the stock vapor molecular weight, E_{Mv}.

A.4.5 UNCERTAINTY IN THE TEST ENCLOSURE LOSS RATE

The per unit uncertainty in the test enclosure loss rate, E_E, shall be calculated from Equation A-10.

$$E_E = [E_{Qs}^2 + E_{Ds}^2 + (C_o^2 E_{Co}^2 + C_i^2 E_{Ci}^2)/(C_o - C_i)^2]^{0.5} \quad \text{(A-10)}$$

The gas flow rate through the test enclosure, Q_s, the inlet concentration, C_i, and outlet concentration, C_o, may vary during the course of a test. The values used in the loss factor determination shall be based on the mean of the measurements that are recorded during the $^1/_2$ hour steady-state test period. The per unit uncertainties in the mean flow rate, inlet concentration and outlet concentration shall include any known bias errors in the calibration of the measurement equipment, as well as random errors resulting from variations during the steady-state test period.

A.4.6 UNCERTAINTY IN THE TEST ENCLOSURE LOSS FACTOR

The per unit uncertainty in the test enclosure loss factor, E_F, shall be calculated from Equation A-11.

$$E_F = [E_E^2 + E_{P*}^2 + E_{Mv}^2 + E_{Kc}^2]^{0.5} \quad \text{(A-11)}$$

A method for determining the per unit uncertainty in the product factor, E_{Kc}, is not known at this time, and a value of 0 may be assumed.

A.4.7 UNCERTAINTY IN THE DECK-SEAM LOSS FACTOR

The per unit uncertainty in the deck-seam loss factor, E_{Kd}, shall be calculated from Equation A-12.

$$E_{Kd} = [E_F^2 + E_{Ld}^2]^{0.5} \quad \text{(A-12)}$$

A.4.8 UNCERTAINTY IN THE DECK-JOINT LOSS FACTOR

The per unit uncertainty in the deck-joint loss factor, E_{Kj}, may be calculated from Equation A-13.

$$E_{Kj} = [(F / K_j)^2 E_F^2 + (L_d\, K_d / K_j)^2 (E_{Ld}^2 + E_{Kd}^2)]^{0.5} \quad \text{(A-13)}$$

A.5 Example Uncertainty Analysis

This section presents an example uncertainty analysis for a deck-seam loss factor test. While no example uncertainty analysis is presented for a deck-joint loss factor test, it would be performed in a manner similar to the following example uncertainty analysis for a deck-seam loss factor test. Table A-1 summarizes the results of the uncertainty analysis.

A.5.1 UNCERTAINTY IN THE VAPOR PRESSURE CONSTANTS

Calculate A_p:

RVP = 7.4200 psi (from the test data).

From Equation 3:

$$\begin{aligned} A_p &= (15.64) - (0.8742)\, ln\, RVP \\ &= (15.64) - (0.8742)\, ln\, (7.4200) \\ &= 13.888 \end{aligned}$$

Calculate E_{Ap}:

$E_{RVP} = 5.0000 \times 10^{-3}$ (estimate).

From Equation A-3:

$$\begin{aligned} E_{Ap} &= (0.8742)\, E_{RVP}/A_p \\ &= (0.8742)(5.0000 \times 10^{-3})/(13.888) \\ &= 3.1473 \times 10^{-4} \end{aligned}$$

Calculate U_{Ap}:

$$\begin{aligned} U_{Ap} &= E_{Ap}\, A_p \\ &= (3.1473 \times 10^{-4})\, (13.888) \\ &= 4.3710 \times 10^{-3} \end{aligned}$$

Calculate B_p:

RVP = 7.4200 psi (from the test data).

From Equation 4:

$$\begin{aligned} B_p &= (8742) - (1049)\, ln\, RVP \\ &= (8742) - (1049)\, ln\, (7.4200) \\ &= 6{,}639.6°R \end{aligned}$$

Calculate E_{Bp}:

$E_{RVP} = 5.0000 \times 10^{-3}$ (estimate).

Table A-1—Summary of Example Uncertainty Analysis Results

Description	Symbol	Units	Value	Notes
Reid vapor pressure	RVP	psi	7.4200	Test data
	U_{RVP}	psi	3.7100 x 10^{-2}	
	E_{RVP}	dimensionless	5.0000 x 10^{-2}	Estimate
Vapor pressure constant	A_p	dimensionless	13.888	Equation 3
	U_{Ap}	dimensionless	4.3710 x 10^{-3}	
	E_{Ap}	dimensionless	3.1473 x 10^{-4}	Equation A-3
Vapor pressure constant	B_p	°R	6,639.6	Equation 4
	U_{Bp}	°R	5.2450	
	E_{Bp}	dimensionless	7.8996 x 10^{-4}	Equation A-4
Liquid temperature	T_l	°F	69.82	Test data
	T_l	°R	529.49	Equation 7
	U_{Tl}	°R	5.0000 x 10^{-1}	Estimate
	E_{Tl}	dimensionless	9.4430 x 10^{-4}	
Vapor pressure	P	psia	3.8509	Equation 8
	U_P	psia	6.1788 x 10^{-2}	
	E_P	dimensionless	1.6045 x 10^{-2}	Equation A-5
Atmospheric pressure	P_a	psia	14.342	Test data
	U_{Pa}	psia	7.1709 x 10^{-2}	
	E_{Pa}	dimensionless	5.0000 x 10^{-3}	Estimate
Ratio of vapor pressure to atmospheric pressure	R_p	dimensionless	0.26851	Equation A-6
	U_{Rp}	dimensionless	4.5126 x 10^{-3}	
	E_{Rp}	dimensionless	1.6806 x 10^{-2}	Equation A-7
Vapor pressure function	P^*	dimensionless	0.078009	Equation 9
	U_{P^*}	dimensionless	1.5329 x 10^{-3}	
	E_{P^*}	dimensionless	1.9650 x 10^{-2}	Equation A-8
Vapor molecular weight	M_v	lb/lb-mole	85.970	Test data
	U_{Mv}	lb/lb-mole	4.2985 x 10^{-1}	
	E_{Mv}	dimensionless	5.0000 x 10^{-3}	Estimate
Test liquid vapor density	D_s	lb/sft^3	0.22656	Equation 10
	U_{Ds}	lb/sft^3	1.1328 x 10^{-3}	
	E_{Ds}	dimensionless	5.0000 x 10^{-3}	Equation A-9
Inlet concentration	C_i	ppmv	2.7900	Test data
	U_{Ci}	ppmv	8.3700 x 10^{-2}	
	E_{Ci}	dimensionless	3.0000 x 10^{-2}	Estimate

Table A-1—Summary of Example Uncertainty Analysis Results (Continued)

Description	Symbol	Units	Value	Notes
Outlet concentration	C_o	ppmv	2548.0	Test data
	U_{Co}	ppmv	$7.6440 \times 10^{+1}$	
	E_{Co}	dimensionless	3.0000×10^{-2}	Estimate
Gas flow rate	Q_s	sft^3/min	0.038299	Test data
	U_{Qs}	sft^3/min	7.6598×10^{-4}	
	E_{Qs}	dimensionless	2.0000×10^{-2}	Estimate
Test enclosure loss rate	E	lb/min	2.2085×10^{-5}	Equation 11
	U_E	lb/min	8.0449×10^{-7}	
	E_E	dimensionless	3.6428×10^{-2}	Equation A-10
Product factor	K_c	dimensionless	1.0000	Given
	U_{Kc}	dimensionless	0.0000	
	E_{Kc}	dimensionless	0.0000	Estimate
Test enclosure loss factor	F	lb-mole/yr	1.7320	Equation 12
	U_F	lb-mole/yr	7.2208×10^{-2}	
	E_F	dimensionless	4.1690×10^{-2}	Equation A-11
Deck seam length	L_d	ft	10.000	Test data
	U_{Ld}	ft	1.0000×10^{-1}	
	E_{Ld}	dimensionless	1.0000×10^{-2}	Estimate
Deck-seam loss factor	K_d	lb-mole/ft yr	0.17320	Equation 13
	U_{Kd}	lb-mole/ft yr	7.4257×10^{-3}	
	E_{Kd}	dimensionless	4.2873×10^{-2}	Equation A-12
Deck seam pressure difference	P_d	in wc	0.044000	Test data
	U_{Pd}	in wc	2.0000×10^{-3}	Estimate
	E_{Pd}	dimensionless	4.5455×10^{-2}	

From Equation A-4:

$$E_{Bp} = (1049)\, E_{RVP}/B_p$$

$$= (1049)\,(5.0000 \times 10^{-3}) / (6{,}639.6)$$

$$= 7.8996 \times 10^{-4}\ °R$$

Calculate U_{Bp}:

$$U_{Bp} = E_{Bp}\, B_p$$

$$= (7.8996 \times 10^{-4})\,(6{,}639.6)$$

$$= 5.2450°R$$

A.5.2 UNCERTAINTY IN THE VAPOR PRESSURE

Calculate P:

A_p = 13.888 (dimensionless; from Section A.5.1)

B_p = 6,639.6°R (from Section A.5.1)

T_l = 529.49°R (from the test data).

From Equation 8:

$$P = \exp\,[A_p - (B_p/T_l)]$$

$$= \exp\,[(13.888) - (6{,}639.6/529.49)]$$

$$= 3.8509 \text{ psia}$$

Calculate E_P:

E_{Ap} = 3.1473×10^{-4} (from Section A.5.1)

E_{Bp} = 7.8996×10^{-4} (from Section A.5.1)

E_{Tl} = 9.4430×10^{-4} (from the test data).

From Equation A-5:

$$E_P = [A_p^2 E_{Ap}^2 + (B_p/T_l)^2(E_{Bp}^2 + E_{Tl}^2)]^{0.5}$$
$$= [(13.888)^2(3.1473 \times 10^{-4})^2 + (6{,}639.6/529.49)^2 [(7.8996 \times 10^{-4})^2 + (9.4430 \times 10^{-4})^2]^{0.5}$$
$$= 1.6045 \times 10^{-2}$$

Calculate U_P:

$$U_P = E_P P$$
$$= (1.6045 \times 10^{-2})(3.8509)$$
$$= 6.1788 \times 10^{-2} \text{ psia}$$

A.5.3 UNCERTAINTY IN THE RATIO OF VAPOR PRESSURE TO ATMOSPHERIC PRESSURE

Calculate R_p:

P = 3.8509 psia (from Section 4.5.2)

P_a = 14.342 psia (from the test data).

From Equation A-6:

$$R_p = P/P_a$$
$$= (3.8509) / (14.342)$$
$$= 0.26851$$

Calculate E_{Rp}:

E_P = 1.6045×10^{-2} (from Section 4.5.2)

E_{Pa} = 5.0000×10^{-3} (estimate).

From Equation A-7:

$$E_{Rp} = [E_P^2 + E_{Pa}^2]^{0.5}$$
$$= [(1.6045 \times 10^{-2})^2 + (5.0000 \times 10^{-3})^2]^{0.5}$$
$$= 1.6806 \times 10^{-2}$$

Calculate U_{Rp}:

$$U_{Rp} = E_{Rp} R_p$$
$$= (1.6806 \times 10^{-2})(0.26851)$$
$$= 4.5126 \times 10^{-3}$$

A.5.4 UNCERTAINTY IN THE VAPOR PRESSURE FUNCTION

Calculate P^*:

R_p = 0.26851 (from Section A.5.3).

From Equation 9:

$$P^* = R_p/[1 + (1 - R_p)^{0.5}]^2$$
$$= (0.26851)/[1 + (1 - 0.26851)^{0.5}]^2$$
$$= 0.078009$$

Calculate E_{P*}:

E_{Rp} = 1.6806×10^{-2} (from Section 4.5.3).

From Equation A-8:

$$E_{P*} = [1/(1 - R_p)^{0.5}]E_{Rp}$$
$$= [1/(1 - 0.26851)^{0.5}]\,(1.6806 \times 10^{-2})$$
$$= 1.9650 \times 10^{-2}$$

Calculate U_{P*}:

$$U_{P*} = E_{P*} P^*$$
$$= (1.9650 \times 10^{-2})\,(0.078009)$$
$$= 1.5329 \times 10^{-3}$$

A.5.5 UNCERTAINTY IN THE VAPOR DENSITY

Calculate D_s:

P_s = 14.696 psia (constant)

T_s = 519.67°R (constant)

R = 10.731 ft^3 psia / lb-mole °R (constant)

M_v = 85.970 lb/lb-mole (from the test data).

From Equation 10:

$$D_s = P_s M_v / R T_s$$

$$= (14.696)(85.970) / (10.731)(519.67)$$

$$= 0.22656 \text{ lb/sft}^3$$

Calculate E_{Ds}:

$$E_{Mv} = 5.0000 \times 10^{-3} \text{ (estimate).}$$

From Equation A-9:

$$E_{Ds} = E_{Mv}$$

$$= 5.0000 \times 10^{-3}$$

Calculate U_{Ds}:

$$U_{Ds} = E_{Ds} D_s$$

$$= (5.0000 \times 10^{-3})(0.22656)$$

$$= 1.1328 \times 10^{-3} \text{ lb/sft}^3$$

A.5.6 UNCERTAINTY IN THE TEST ENCLOSURE LOSS RATE

Calculate E:

Q_s = 0.038299 sft^3/min (from the test data)

D_s = 0.22656 lb/sft^3 (from Section A.5.4)

C_i = 2.7900 ppmv (from the test data)

C_o = 2548.0 ppmv (from the test data).

From Equation 11:

$$\text{E} = (1 \text{ volume fraction}/106 \text{ ppmv})\, Q_s D_s (C_o - C_i)$$

$$= (10\text{-}6)(0.038299)(0.22656)(2548.0 - 2.7900)$$

$$= 2.2085 \times 10^{-5} \text{ lb/min}$$

Calculate E_E:

E_{Qs} = 2.0000×10^{-2} (estimate)

E_{Ds} = 5.0000×10^{-3} (from Section A.5.5)

E_{Ci} = 3.0000×10^{-2} (estimate)

E_{Co} = 3.0000×10^{-2} (estimate).

From Equation A-10:

$$E_E = [E_{Qs}^2 + E_{Ds}^2 + (C_o^2 E_{Co}^2 + C_i^2 E_{Ci}^2) / (C_o - C_i)^2]^{0.5}$$

$$= [(2.0000 \times 10^{-2})^2 + (5.0000 \times 10^{-3})^2 + ((2548.0)^2(3.0000 \times 10^{-2})^2 + (2.7900)^2(3.0000 \times 10^{-2})^2)/ (2548.0 - 2.7900)^2]^{0.5}$$

$$= 2.2085 \times 10^{-5} \text{ lb/min}$$

Calculate U_E:

$$U_E = E_E E$$

$$= (3.6428 \times 10^{-2})(2.2085 \times 10^{-5})$$

$$= 8.0449 \times 10^{-7} \text{ lb/min}$$

A.5.7 UNCERTAINTY IN THE TEST ENCLOSURE LOSS FACTOR

Calculate F:

E = 2.2085×10^{-5} lb/min (from Section A.5.6)

P^* = 0.078009 (dimensionless; from Section A.5.4)

M_v = 85.970 lb/lb-mole (from the test data)

K_c = 1.0000 (dimensionless; given constant).

From Equation 12:

$$F = (60)(24)(365.25)\, E / P^* M_v K_c$$

$$= (60)(24)(365.25)(2.2085 \times 10^{-5}) / (0.078009)(85.970)(1.0000)$$

$$= 1.7320 \text{ lb-mole/yr}$$

Calculate E_F:

E_E = 3.6428×10^{-2} (from Section A.5.6)

E_{P*} = 1.9650×10^{-2} (from Section A.5.4)

E_{Mv} = 5.0000×10^{-3} (estimate)

E_{Kc} = 0 (assumed).

From Equation A-11:

$$E_F = [E_E^2 + E_{P*}^2 + E_{Mv}^2 + E_{Kc}^2]^{0.5}$$

$$= [(3.6428 \times 10^{-2})^2 + (1.9650 \times 10^{-2})^2 + (5.0000 \times 10^{-3})^2 + (0)^2]^{0.5}$$

$$= 4.1690 \times 10^{-2}$$

Calculate U_F:

$$U_F = E_F F$$
$$= (4.1690 \times 10^{-2})\ (1.7320)$$
$$= 7.2208 \times 10^{-2} \text{ lb-mole/yr}$$

A.5.8 UNCERTAINTY IN THE DECK-SEAM LOSS FACTOR

Calculate K_d:

F = 1.7320 lb-mole/yr (from Section A.5.7)

L_d = 10.000 ft (from the test data).

From Equation 13:

$$K_d = F / L_d$$
$$= (1.7320) / (10.000)$$
$$= 0.17320 \text{ lb-mole/ft yr}$$

Calculate E_{Kd}:

E_F = 4.1690×10^{-2} (from Section A.5.7)

E_{Ld} = 1.0000×10^{-2} (estimate).

From Equation A-12:

$$E_{Kd} = [E_F^2 + E_{Ld}^2]^{0.5}$$
$$= [(4.1690 \times 10^{-2})^2 + (1.0000 \times 10^{-2})^2]^{0.5}$$
$$= 4.2873 \times 10^{-2}$$

Calculate U_{Kd}:

$$U_{Kd} = E_{Kd} K_d$$
$$= (4.2873 \times 10^{-2})\ (0.17320)$$
$$= 7.4257 \times 10^{-3} \text{ lb-mole/ft yr}$$

A.5.9 SUMMARY OF THE UNCERTAINTY ANALYSIS

The deck-seam loss factor, K_d, that resulted from the test data of this example can be stated as follows:

K_d = 0.17320, ±0.0074257 lb-mole/ft yr

at a test enclosure pressure difference of:

P_d = 0.0440, ±0.0020 in water column (from the test data).

APPENDIX B—METRIC UNITS

B.1 General

To covert the inch-pounds units employed in the text to equivalent SI units of the International System of Units, the guidelines of the API *Manual of Petroleum Measurement Standards*, Chapter 15, shall be followed. The unit of length is either the kilometer, designated km, or the meter, designated m. The unit of mass is the kilogram, designated kg. The unit of force is the newton, designated N. The unit of time is either the hour, designated hr, or the year designated yr. The unit of temperature is the degree Celsius, designated °C, or the degree Kelvin, designated °K.

B.2 Pressure

The text employs the units of pounds force per square inch, designated psi, or inches of water column, designated in wc, for pressure. The equivalent SI unit for pressure is the kilopascal, designated kPa.

B.3 Deck-Seam Loss Factor

The text employs the units of pounds-moles per foot year, designated lb-mole/ft yr, for the deck-seam loss factor, K_d. The equivalent SI units are kilogram-moles per meter year, designated kmol/m yr.

The use of the deck-seam loss factor, K_d, to determine deck seam losses is described in the API *Manual of Petroleum Measurement Standards*, Chapter19.2.

To determine the deck-seam loss rate in the inch-pound units of pound-moles per year, designated lb-mole/yr for a floating roof tank, the deck-seam loss factor, K_d, with units of pounds-moles per foot year, designated lb-mole/ft yr, must be multiplied by the following four factors: the deck seam length, L_d, with units of feet of deck seam, designated ft; the dimensionless vapor pressure function, P^*; and the dimensionless product factor, K_c.

To determine the deck-seam loss rate in SI units of kilogram-moles per year for a floating roof tank, the deck-seam loss factor, K_d, with units of kilogram-mole per meter year, designated kmol/m yr, must be multiplied by the following four factors: the deck seam length, L_d, with units of meters of deck seam, designated m; the dimensionless vapor pressure function, P^*; and the dimensionless product factor, K_c.

B.4 Deck-Joint Loss Factor

The text employs the units of pound-moles per year, designated lb-mole/yr, for the deck-joint loss factor, K_j. The equivalent SI units are kilogram-mole per year, designated kmol/yr.

The use of the deck-joint loss factor, K_j, to determine deck joint losses is described in the API *Manual of Petroleum Measurement Standards*, Chapter 19.2.

To determine the deck-joint loss rate in the inch-pound units of pound-moles per year, designated lb-mole/yr, for a floating roof tank, the deck-joint loss factor, K_j, with units of pound-moles per year, designated lb-mole/yr, is multiplied by the following three factors: the dimensionless number of deck joints of a particular type that are on the floating roof deck, N_j; the dimensionless vapor pressure function, P^*, and the dimensionless product factor, K_c.

To determine the deck-joint loss rate in the SI units of kilogram-moles per year, designated kmol/yr, for a floating roof tank, the deck-joint loss factor, K_j, with units of kilogram-moles per year, designated kmol/yr, is multiplied by the same three dimensionless factors, N_j, P^*, and K_c, that were used with the in-pound units.

APPENDIX C—BIBLIOGRAPHY

The following is a list of related references not cited in the text.

C.1 API References

Manual of Petroleum Measurement Standards:

Chapter 19.1 "Evaporative Loss From Fixed-Roof Tanks," Second Edition, October 1991.

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[2]ASTM International, 100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428.

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