Manual of Petroleum Measurement Standards Chapter 19.3—Evaporative Loss Measurement

Part B—Air Concentration Test Method—Rim-Seal Loss Factors for Floating-Roof Tanks

FIRST EDITION, AUGUST 1997

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American Petroleum Institute

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FOREWORD

This standard provides rules for testing the rim seals of external, covered, and internal floating roofs under laboratory conditions to provide evaporative rim-seal loss factors. It was prepared by Task Group II of the API Environmental Technical Advisory Group (ETAG).

Testing programs conducted by API, which began in the mid-1970s and extended through 1982, provided the information on which the current evaporative rim-seal loss factors are based for common, generic types of external, covered, and internal floating-roof rim seals. These rim-seal loss factors are published in API Publication 2517, *Evaporative Loss From External Floating-Roof Tanks*, API Publication 2519, *Evaporation Loss From Internal Floating-Roof Tanks*, and in API *Manual of Petroleum Measurement Standards*, Chapter 19.2, "Evaporative Loss From Floating-Roof Tanks," for use in estimating the evaporative loss of petroleum stocks from external, covered, and internal floating-roof tanks. These rim-seal loss factors and the test methods used to develop them have been widely accepted by oil companies, manufacturers, industry groups, regulatory agencies, and general interest groups. API has not, however, tested or developed evaporative rim-seal loss factors for proprietary designs of individual manufacturers. By publishing this test method, API is making the test method available to interested parties who wish to test particular rim seals under the auspices of 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 API. The requirements to qualify for licensure are presented in 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 then be conducted in accordance with API *Manual of Petroleum Measurement Standards*, Chapter 19.3, Part F, "Evaporative Loss Factor for Storage Tanks Certification Program."

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0 Introduction

The purpose of this standard is to establish a uniform method for use in measuring evaporative rim-seal loss factors of rim seals used on external, covered, and internal floating-roof tanks. These rim-seal loss factors are to be determined in terms of loss rate, seal gap area, and wind speed 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 rim seals. 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 rim-seal loss factors for rim seals used on external and internal floating-roof tanks. The test method involves passing a controlled flow rate of air through a test chamber that contains a test liquid and a test rim seal, and measuring the concentration of the test liquid vapor in the air streams entering and leaving the test chamber. 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 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 determine the applicability of regulatory limitations prior to use.

2 Normative 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 NORMATIVE STANDARDS

API

Manual of Petroleum Measurement Standards, Chapter 19.3, Part F, "Evaporative Loss Factor for Storage Tanks Certification Program," First Edition, March 1997

Manual of Petroleum Measurement Standards, Chapter 19.3, Part G, "*Certified Loss Factor Testing Laboratory Registration,*" First Edition, March 1997

2.2 ASTM NORMATIVE STANDARDS

ASTM[1]

- D323 *Test Method for Vapor Pressure of Petroleum Products (Reid Method)*
- E220 *Method for Calibration of Thermocouples by Comparison Techniques*
- E230 *Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples*

2.3 ASME NORMATIVE STANDARDS

ASME[2]

- MFC-3M *Measurement of Fluid Flow in Pipes Using Orifice, Nozzle and Venturi*

3 Terminology

3.1 DEFINITIONS

3.1.1 ACT facility: The entire facility used in the Air Concentration Test (ACT) method. The ACT facility includes the test chamber, the sensors and data acquisition system, the air blower, the air inlet and outlet ducts, and the test liquid storage.

3.1.2 air concentration test method: The test method used to establish evaporative rim-seal loss factors for rim seals used on external, covered, and internal floating-roof tanks that involves passing a controlled flow rate of air through a test chamber that contains a test liquid and a test rim seal, and measuring the concentration of the test liquid vapor in the air streams entering and leaving the test chamber.

3.1.3 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

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

[2]American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10017.

of the American Petroleum Institute Standard 650, *Welded Steel Tanks for Oil Storage*.

3.1.4 data acquisition: The process of receiving signals from the sensors, determining the values corresponding to the signals, and recording the results.

3.1.5 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.

3.1.6 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.

3.1.7 deck seam: Certain types of internal floating roofs are constructed of deck sheets or panels that are joined by mechanical means at deck seams. Such mechanically joined seam devices 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 seam devices do not have an associated deck seam loss.

3.1.8 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.

3.1.9 external floating roof: A floating roof that is exposed to the 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 American Petroleum Institute Standard 650, *Welded Steel Tanks for Oil Storage*.

3.1.10 internal floating roof: A floating roof that is not exposed to the 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 American Petroleum Institute Standard 650, *Welded Steel Tanks for Oil Storage*.

3.1.11 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.

3.1.12 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 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 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.

3.1.15 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.

3.1.16 sensor: An instrument that senses the 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.

3.1.17 standing storage evaporative loss: Loss of stored liquid stock 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 support legs. This does include, however, evaporative losses from the rim seal, deck seams, and deck fittings.

3.1.18 test chamber: The portion of the ACT facility that contains the test rim seal and the test liquid.

3.1.19 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 average atmospheric pressure at the storage location. The vapor pressure function, the stock 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 D, Metric Units.

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. The unit of electromotive force is the volt, designated *v*.

3.2.3 Velocity

The unit of velocity is the mile per hour, designated mi/hr or mph.

3.2.4 Pressure

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

3.2.5 Rim-Seal Loss Factors

The unit of reporting rim-seal loss factors is the pound-mole per foot of tank diameter per year, designated lb-mole/ft yr.

The units of the rim-seal loss factor, K_r, 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 tank diameter per year units of the rim-seal loss factor to a loss rate in terms of actual pound-moles per foot of tank diameter per year, the rim-seal loss factor, K_r, is multiplied by the dimensionless coefficients P^*, which is a function of the product vapor pressure and atmospheric pressure, and K_c, the product factor.

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 tank diameter per year to pounds per year of a given liquid product, the loss rate ($K_r P^* K_c$) is multiplied by the tank diameter, D, and the molecular weight of the liquid product in its vapor phase, M_v, with molecular weight having units of pounds per pound-mole. Additional information on this formula may be found in API Publications 2517 [7] and 2519 [11], and in API *Manual of Petroleum Measurement Standards,* Chapter 19.2 [12].

Note: The numbers in parentheses indicate a reference in the Appendix E, Bibliography.

3.3 NOMENCLATURE

Symbol	Description	Units
A_g	Rim-seal gap area	ft^2
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 chamber inlet air	ppmv
C_o	Concentration of hydrocarbon vapor in the test chamber outlet air	ppmv
D	Tank diameter	ft
D_v	Density of hydrocarbon vapor in the test chamber outlet air	lb/ft^3
F_g	Rim-seal gap area factor	ft^2/ft
K_c	Product factor	dimensionless
K_r	Rim-seal loss factor	lb-mole/ft yr
L	Rim-seal loss rate	lb/hr
L_c	Length of the test chamber	ft
L_r	Rim-seal loss rate	lb/yr
L_s	Length of the test rim seal	ft
M_v	Molecular weight of test liquid vapor	lb/lb-mole
P	Vapor pressure of the test liquid	psia
P_a	Atmospheric pressure	psia
P_d	Static pressure in the outlet duct at the air flow rate sensor	psia
P^*	Vapor pressure function	dimensionless
Q_a	Volumetric flow rate of the outlet air at actual conditions	acfm
R	Universal gas constant (10.73)	ft^3 psia/lb-mole °R
T_d	Temperature of the air in the outlet duct at the air flow rate sensor	°R or °F
T_l	Stock liquid temperature	°R or °F
V	Wind speed	mph

4 Summary of Test Method

The test method described in this standard uses a mass balance procedure to measure a rate of evaporative loss. A test chamber is fitted with a test rim seal. Spacers are placed between the test rim seal and the simulated tank shell of the test chamber to create a specified rim-seal gap area. The area below the test rim seal is filled to an appropriate height with a volatile hydrocarbon test liquid of known properties, such as normal-hexane or isohexane. A prescribed level of air flow rate through the test chamber is set. The concentration of the test liquid vapors in the air is measured at the test chamber inlet and outlet. A mass balance is then used to determine the loss rate of the volatile hydrocarbon test liquid vapor through the rim seal. The loss rate is then factored for the properties of the test liquid and the length of the test rim seal in order to determine an evaporative rim-seal loss factor for the test rim seal at that seal gap area.

5 Significance and Use

This test method establishes a procedure for measuring the evaporative rim-seal loss factor of rim seals that are used on external, covered, and 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 rim seal tested. The laboratory approval procedure, the test method, and the evaluation method together constitute a procedure by which manufacturers of floating-roof rim seals may obtain API-certified loss factors for rim seals 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 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 rim seals that have a loss rate lower than the specified tolerance of the instruments.

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

7 Test Apparatus

7.1 TEST APPARATUS SCHEMATIC

Figures 1, 2, and 3 are schematics of the test apparatus that is to be used to obtain the measurements necessary for developing a certified evaporative rim-seal loss factor for a test rim seal of an external, covered, or internal floating roof. The test apparatus is comprised of certain test equipment and instrumentation arranged in a test room.

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 room.

7.2.2 Air Temperature Control System

The test room shall have a dedicated temperature controller 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 Chamber Air

The air that is directed through the test chamber may be drawn from an area of the building outside of the test room in order to avoid disturbing the control of the air temperature within the test room. The temperature of the air in the test chamber shall be maintained within ±10°F of the temperature of the air in the test room.

7.3 TEST CHAMBER

The test chamber shall be a curved length of duct through which air may be directed by means of a blower, as illustrated in Figure 1. The curvature of the test chamber shall be based on the shell curvature of a 100-foot-diameter storage tank. The test chamber shall have a generally rectangular cross section so as to readily accommodate openings. There shall be openings in the sides of the test chamber to allow access to the test rim seal for inspection and modification and also to allow for viewing the test rim seal while the test is in progress. The top of the test chamber shall be removable to

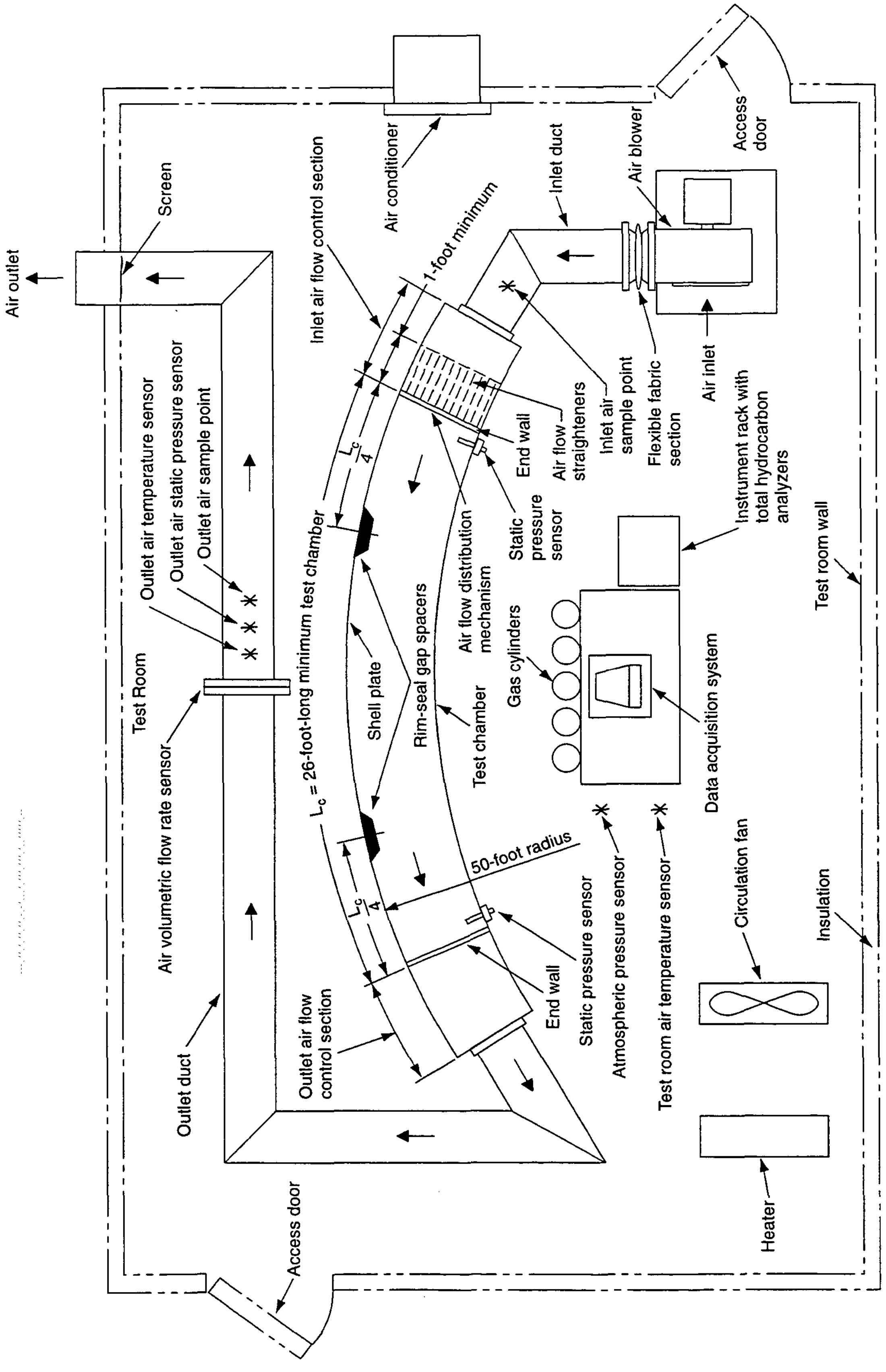


Figure 1—Plan View of the Air Concentration Test Facility

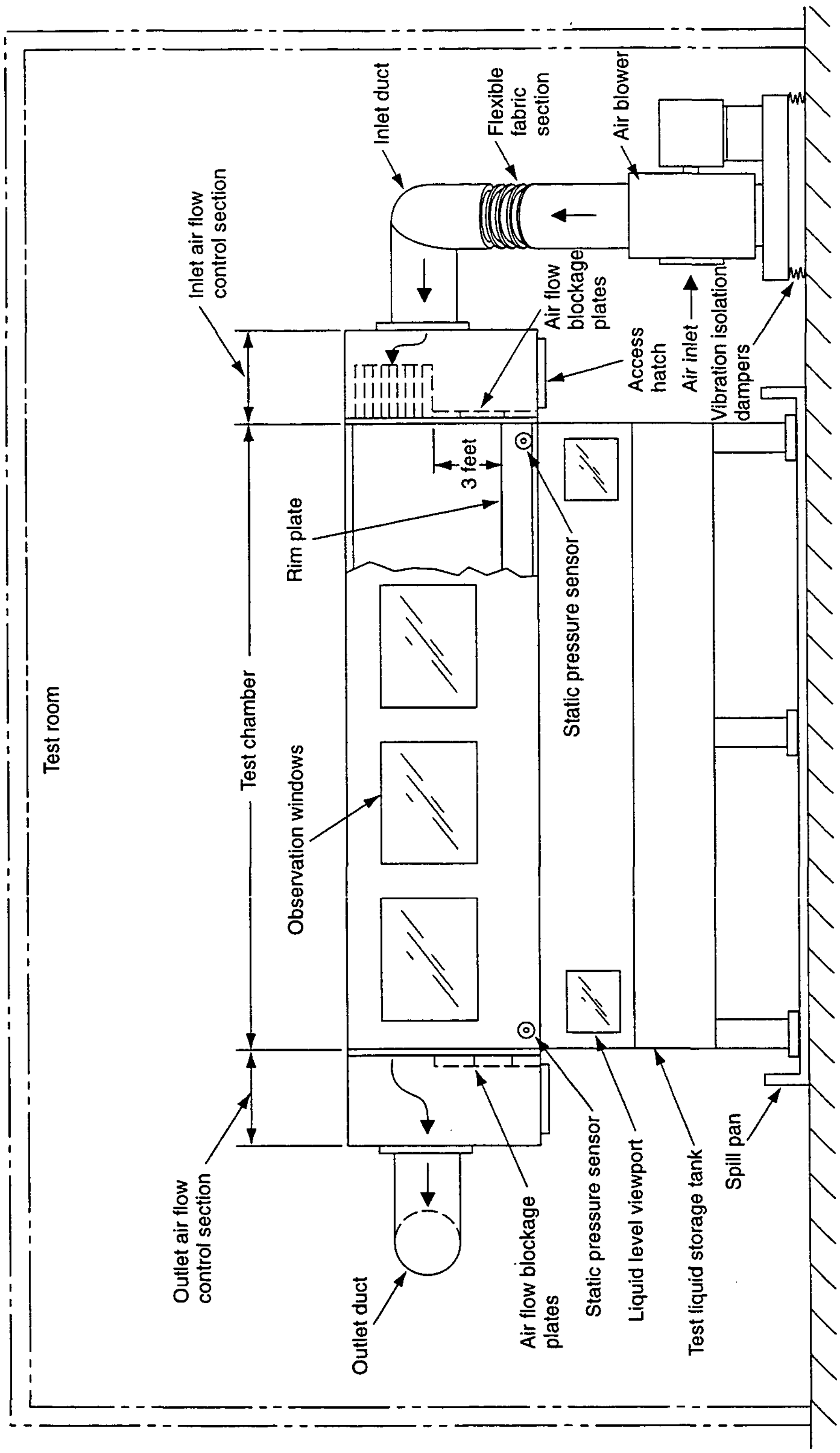


Figure 2—Elevation View of the Air Concentration Test Facility

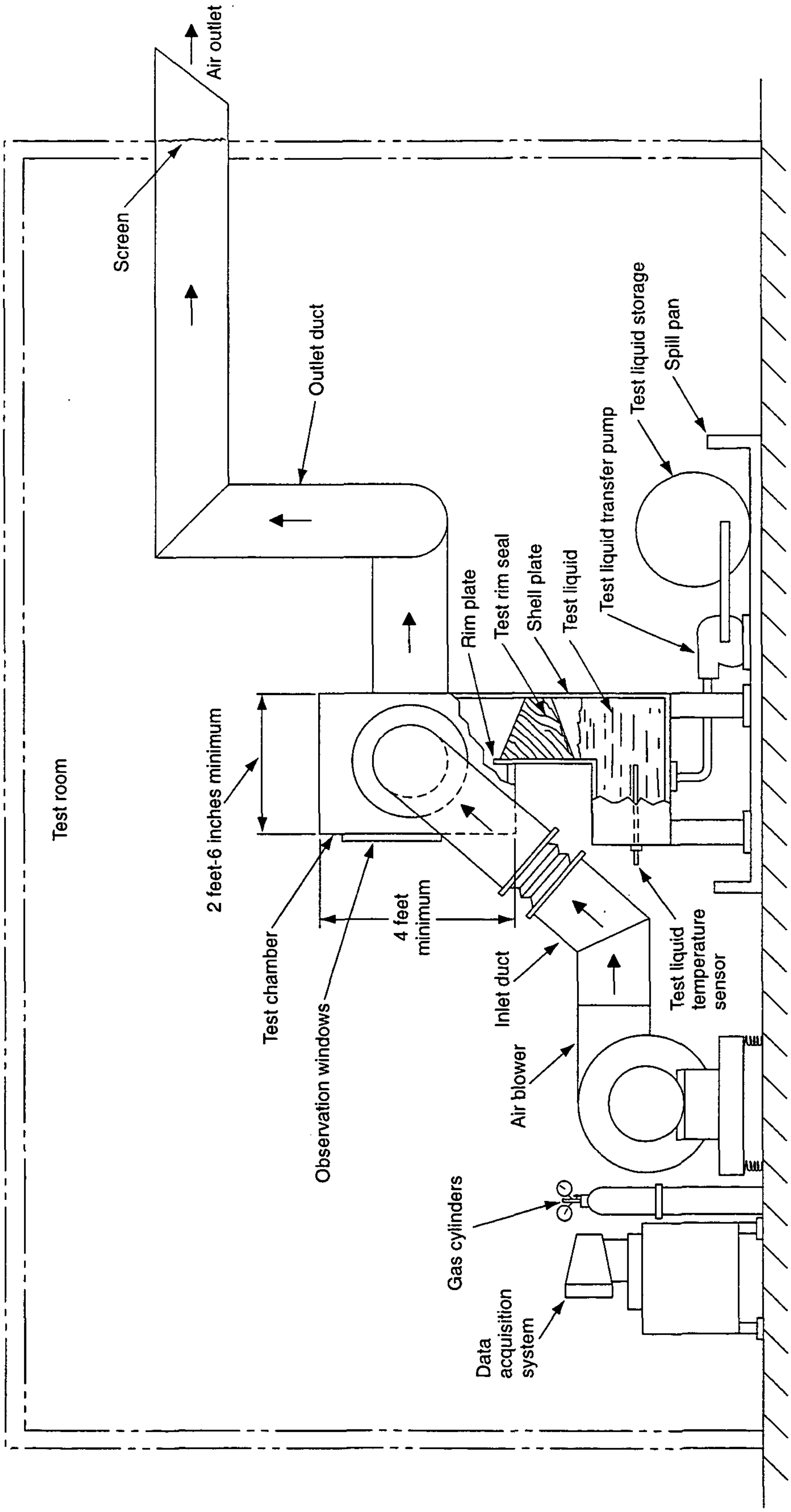


Figure 3—Section View of the Air Concentration Test Facility

allow for test rim seal installation and removal. The test chamber shall have a cross section above the simulated floating roof rim that is at least 2½-feet wide by 4-feet high and shall be of sufficient length to accommodate a test rim seal section that has an arc length of at least 26 feet.

The test chamber shall be fitted with a thermocouple to measure the temperature of the test liquid within 3 inches below the test liquid surface.

7.4 INLET AIR FLOW CONTROL SECTION

An inlet air flow control section shall be installed between the inlet of the test chamber and the connection to the inlet duct. The air flow pattern in the test chamber shall be controlled by an air flow distribution mechanism and air flow straighteners that are located in the inlet air flow control section. An access hatch may be installed in this section to facilitate inspection and cleaning of the air flow distribution mechanism and air flow straighteners.

7.4.1 Air Flow Distribution Mechanism

The air flow distribution mechanism shall consist of air flow blockage plates located below the air flow straighteners at the discharge of the inlet air flow control section, as shown in Figures 1 and 2. The distance from the top of the rim plate to the bottom of the air flow straighteners shall be 3 feet.

7.4.2 Air Flow Straighteners

Air flow straighteners shall be installed in the inlet air flow control section, as shown in Figures 1 and 2. The air flow straighteners shall be at least 1-foot-long and shall consist of air flow straightening devices, such as a bank of 2-inch-diameter tubes.

7.5 OUTLET AIR FLOW CONTROL SECTION

An outlet air flow control section shall be installed between the discharge of the test chamber and the connection to the outlet duct. The outlet air flow control section shall be constructed in a manner similar to that of the inlet air flow control section and shall also have a similar air flow distribution mechanism at the location where this section is joined to the test chamber, as shown in Figures 1 and 2.

7.6 AIR BLOWER

Air movement in the test chamber shall be provided by an air blower located at the upstream end of the inlet duct, as shown in Figure 1. The air blower shall be capable of providing variable air flow rates corresponding to equivalent air wind speeds ranging from 0.5 to 15 mph. The air blower shall be capable of maintaining the wind speed at a constant level within ±10 percent during a test period.

7.7 VIBRATION DAMPING

The transmission of vibrations to the test chamber and data acquisition system shall be minimized by installing vibration damping equipment on the air blower. The air blower shall be mounted on vibration isolation dampers, and a flexible fabric section shall be installed between the discharge of the air blower and the inlet duct.

7.8 RIM SEALS

The rim seal to be tested shall be mounted on the simulated floating roof rim using the assembly and installation procedures normally used for the rim seal, as specified by the rim seal manufacturer. The only exception to this use of normal procedures involves the sealing method for the ends of the test rim seal. At each end of the section of test rim seal, the test rim seal must be joined and sealed to the end wall of the test chamber to eliminate emission end effects. Sealing details for these end joints shall be documented in the report of test results and should be installed in a manner so as to not affect the emission characteristics of the test rim seal.

The surfaces of the test rim seal and the test chamber shell plate shall be clean and free from oil or other material that may affect the rim-seal loss factor test results.

A leak-tightness test may be performed on the test rim seal to ensure that there are no leak paths through the two end joints. An example of such a leak-tightness test consists of applying a slight gas pressure in the vapor space under the rim seal. A leak detection liquid (typically a soap-like liquid that will form bubbles at vapor leaks) may then be applied at the end joints. If no bubbles are detected, it can be assumed that no significant end joint emission leaks are present.

7.9 TEST LIQUID

The test liquid shall be maintained at a level relative to the test rim seal that corresponds to that which is typical of industry practice for the rim seal 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 the Reid vapor pressure of the mixture in accordance with ASTM D323.

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.

Test rim seals that normally extend into the liquid product on a storage tank shall be mounted in the test chamber in a manner that permits free flow of the test liquid to all rim space areas below the test rim seal. For example, when testing a mechanical-shoe primary seal, the layer of test liquid that is floating on water must extend below the bottom of the shoe.

7.10 EMPTYING AND FILLING

All liquid-level fittings of the test chamber, including those for emptying and filling, must be leak tight. A method of indicating the liquid level in the test chamber must be provided to control 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.

7.11 SPILL PAN

It is advisable to place a spill pan under the test chamber to collect any spillage of test liquid that may occur during filling and emptying operations.

8 Test Item

8.1 TEST ITEM CONSTRUCTION

The items to be tested according to this test method are rim seals for external, covered, and internal floating-roof tanks. Items to be tested shall be full-scale samples of the rim seals. These shall be constructed according to the manufacturer's standard practice and shall include all features typical to actual use.

8.2 TEST RIM SEAL ATTACHMENT

The rim seal to be tested shall be attached to the test chamber in a manner similar to its attachment to a floating-roof rim in practice. Test rim seals that normally extend into the liquid product on a floating roof shall be mounted in a similar manner on the test chamber.

8.3 TEST RIM SEAL END CONNECTIONS

The ends of the test rim seal shall be sealed to the end walls of the test chamber. A suitable sealant or caulk may be used for this purpose.

8.4 TALL RIM SEALS

Some test rim seals (especially secondary seals) may extend well above the floating-roof rim of the test chamber. For these test rim seals, care must be taken to ensure that the air flow is not allowed to pass under the test rim seal due to the projection of the test rim seal above the height of the test chamber end wall.

9 Preparation Of Apparatus

9.1 TEST ITEM PLACEMENT

Install the test rim seal in the test chamber, as described in 7.8 and 8.2. Fill the test chamber with test liquid to the proper level, as described in 7.9. Insert rim-seal gap spacers between the test rim seal and the shell plate to create the required gap area, as described in 11.1.

9.2 TEST ROOM AIR TEMPERATURE CONTROL

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

9.3 AIR BLOWER STARTUP

Start the air blower and adjust its air flow rate to achieve the specified wind speed in the test chamber, as indicated by the measurement of the air flow rate.

9.4 STEADY-STATE OPERATION

Start the data acquisition system, and record the appropriate temperatures, pressures, and concentrations over a period of time until a steady evaporative loss rate is achieved. Following this initial startup period during which the evaporation rate stabilizes, the subsequent test data recorded by the data acquisition system (as described in 11.3) shall constitute the record of test data that is to be used in calculating the rim-seal loss factor. The test period of steady loss rate shall not be less than 1 hour.

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.

The demonstrated accuracy of the sensors shall be based on the readings indicated by the data acquisition system,

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 air in the test room	Thermocouple	±0.5°F	6 months
Average bulk temperature of the test liquid	Thermocouple	±0.5°F	6 months
Temperature of the air in the outlet duct	Thermocouple	±0.5°F	6 months
Concentration of the hydrocarbon vapor in the inlet duct	Total hydrocarbon analyzer	±1%	Every test
Concentration of the hydrocarbon vapor in the outlet duct	Total hydrocarbon analyzer	±1%	Every test
Atmospheric pressure in the test room	Pressure sensor	±0.05 psia	6 months
Orifice plate pressure drop	Differential pressure sensor	±0.5%	6 months
Pitot tube differential pressure	Differential pressure sensor	±0.5%	6 months
Test chamber static pressure rise	Differential pressure sensor	±0.5%	6 months
Outlet duct static pressure	Pressure sensor	±0.5%	6 months
Test chamber static pressure	Pressure sensor	±0.5%	6 months

thereby providing verification of the indicator as well as the sensor. Calibration standards shall be traceable to 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 MEASUREMENT

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 in the outlet duct.

10.3.1.1 Test Liquid Temperature

At least one thermocouple shall be located within 3 inches below the test liquid surface in the test chamber to measure the bulk temperature of the test liquid, as shown in Figure 3.

10.3.1.2 Test Room Temperature

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

10.3.1.3 Outlet Duct Air Temperature

A thermocouple shall be located in the outlet duct to measure the temperature of the air passing the air volumetric flow rate sensor in the outlet duct, 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 in ASTM E230. The observed values shall not vary from the true values by more than ±0.5°F.

10.4 WIND SPEED MEASUREMENT

The effective wind speed shall be based on the pressure-flow characteristics of the specific test chamber being used. Appendix B presents the procedure that shall be used to determine the wind speed calibration of the test chamber. This procedure presents a relationship that relates the ambient wind speed to the test chamber static pressure rise, which in turn is related to the air volumetric flow rate through the test chamber. As a result, the air volumetric flow rate is used to set the desired test wind speed condition.

10.4.1 Air Volumetric Flow Rate Measurement

The air volumetric flow rate shall be measured in the outlet duct using an orifice plate, a pitot tube, or some other suitable sensor. The air volumetric flow rate sensor shall be manufactured and placed in the outlet duct in accordance with the manner that is described in ASME MFC-3M.

10.4.2 Air Volumetric Flow Rate Sensor Calibration

Orifice plates, pitot tubes, and similar air volumetric flow rate sensors shall be considered primary instruments and need not be calibrated.

10.5 CONCENTRATION MEASUREMENT

The concentration of the test liquid vapors in the inlet duct and outlet duct shall be measured with total hydrocarbon analyzers (THA) or equivalent instruments. The THA instruments shall be calibrated during a test at intervals not exceeding 12 hours using zero and span gases of known certified composition. Additionally, the THA instruments shall be calibrated within one hour before beginning a test.

10.6 ATMOSPHERIC PRESSURE MEASUREMENT

Atmospheric pressure shall be sensed with a 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.

10.6.1 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.

10.6.2 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.

10.7 STATIC PRESSURE MEASUREMENT

The air static pressure shall be measured in the test chamber and in the outlet duct at the air volumetric flow rate sensor. High-precision electronic pressure sensors shall be used for these measurements, and their output signal shall be recorded directly by the data acquisition system. The measured pressures shall not exceed the sensor's measurable range, even during brief periods of pressure fluctuations. Also, the measured pressures shall not be below 10 percent of the sensor's full-scale range. The static pressure measurement sensors shall be calibrated at least every 6 months. The accuracy of the static pressure sensors shall be based on the readings indicated by the data acquisition system.

10.8 DIFFERENTIAL PRESSURE MEASUREMENT

The air differential pressure shall be measured across the outlet duct air volumetric flow rate sensor (for example, orifice plate, pitot tube, and so forth) and also across the test chamber. The test chamber air differential pressure shall be considered an air static pressure rise from the inlet to the outlet of the test chamber at locations adjacent to the rim plate. The measured air differential pressures shall not exceed the sensor's measurable range, even during brief periods of pressure fluctuations. Also, the measured differential pressures shall not be below 10 percent of the sensor's full-scale range. The differential pressure sensors shall be calibrated at least every 6 months. The accuracy of the differential pressure sensors shall be based on the readings indicated by the data acquisition system.

11 Test Procedure

11.1 RIM-SEAL GAPS

Insert the rim-seal gap spacers with the specified rim-seal gap area between the test rim seal and the shell plate of the test chamber.

A rim-seal gap is defined as any space, or opening, between the tank shell and the rim seal that provides an unobstructed path from the top of the seal to the stored product liquid surface or to a position beneath the rim seal for inserting a 0.125-inch diameter probe.

11.1.1 Rim-Seal Gap Area Factor

The rim-seal gap area, A_g, is the total cumulative area of the rim-seal gaps. The rim-seal gap area factor, F_g, is the total cumulative area of rim-seal gaps, A_g, divided by the tank diameter, D. The units of the rim-seal gap area factor are in.^{2} gap area/ft tank diameter, or in.^{2}/ft.

11.1.2 Rim-Seal Gap Spacers

To create a specified rim-seal gap area, gap spacers may be inserted between the rim seal and the inside surface of the tank shell. Gap spacers may consist of spacer bars or spacer plates. When spacer bars are used, they must not create a blockage to circumferential air flow at the location of the spacer bar. When spacer plates are used, they should have sides that taper from the widest gap width back to the tank shell.

Gap spacers used in the primary seal should not create a gap that exceeds 1.5 inches. Gap spacers used in the secondary seal should not create a gap that exceeds 0.5 inch. If larger gap areas are required for testing, the circumferential length at which the rim seal is intentionally gapped should be extended.

11.1.3 Rim-Seal Gap Spacer Locations

When rim-space gap spacers are used to create a specified rim-seal gap area factor, F_g, two equally sized rim-seal gap spacers shall be used, each located from the ends of the test chamber at positions that are one-quarter of the length of the test chamber, L_c, as shown in Figure 1.

11.1.4 Rim-Seal Gap Area Factor Test Conditions

Tests shall be conducted at the specified values of the rim-seal gap area factor, F_g. The rim-seal gap area factor shall be assigned a value of zero when no rim-seal gap spacers are inserted and when the only gaps present are those that result from the fit of the rim seal to the inside surface of the tank shell.

Example

As an example in determining the required rim-seal gap area, A_g, for a rim-seal gap area factor, F_g, assume that the length of the test chamber, L_c, is 26 feet, as shown in Figure 1. The test chamber length represents half of the circumference of a floating roof, as discussed in SB.4, where the test chamber inlet represents the windward side of a floating roof and the test chamber outlet represents the leeward side of a floating roof. The test chamber thus represents a tank whose diameter, D, is (2)(26.00)/(3.142) = 16.55 ft. If the rim-seal gap area factor, F_g, is 1.0 in.^{2} of gap/ft of tank diameter, then the required rim-seal gap area, A_g, is 16.55 in.^{2} for a tank whose diameter is 16.55 ft. Since the test chamber represents only half of the circumference of a floating roof, and since two equally-sized rim-seal gap spacers are required to be installed in the test chamber, each gap spacer is required to have an area of 4.138 in.^{2} This gap area could be produced, for example, by a gap spacer that is 0.5 inches wide and about 8.267 inches long. The exact circumferential length of the gap spacer depends upon the shape of the taper at each end of the gap spacer.

11.2 LEVELS OF WIND SPEED

Tests shall be conducted at the minimum number of wind speeds of approximately 0.5, 5, 10 and 15 mph for each rim seal and rim-seal gap area that is tested. Tests at additional wind speeds can sometimes help in determining the wind speed dependency of the rim-seal loss factor. The test results at a wind speed of 0.5 mph represents conditions typical of those of an internal floating roof and are called zero wind speed tests, as discussed in C.3.

11.3 DATA TO BE RECORDED

11.3.1 Test Rim Seal

A description of the test rim seal shall be recorded, including the name of the manufacturer and any model name or number. Dimensions of the test rim seal shall be recorded on a drawing, and a drawing shall be made of the end sealing arrangement. Photographs shall be taken to document the test rim seal, its installation procedure, and its final arrangement in the test chamber.

11.3.2 Instruments

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

11.3.3 Test Data

Test data for each determination shall be recorded. All 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.

11.3.3.1 Temperature

The temperature of the test liquid, the temperature of the air in the test room, and the temperature of the air in the outlet duct shall be recorded at intervals of 5 minutes or less.

11.3.3.2 Test Chamber Static Pressure Rise

The static pressure rise from the inlet to the outlet of the test chamber shall be recorded at intervals of 5 minutes or less.

11.3.3.3 Air Volumetric Flow Rate

The air volumetric flow rate through the outlet duct shall be recorded at intervals of 5 minutes or less.

11.3.3.4 Outlet Duct Static Pressure

The static pressure in the outlet duct at the air flow rate sensor shall be recorded at intervals of 5 minutes or less.

11.3.3.5 Total Hydrocarbon Vapor Concentration

The total hydrocarbon vapor concentration of the air in the inlet duct and in the outlet duct shall be recorded at intervals of 5 minutes or less.

11.3.3.6 Atmospheric Pressure

The atmospheric pressure in the test room shall be recorded at intervals of 5 minutes or less.

11.3.3.7 Test Liquid Vapor Pressure

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

11.3.4 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 rim-seal gap area and test chamber liquid level.

11.4 DURATION OF TEST

The emission characteristics of a test rim seal may change after a change is made in the test conditions (for example, wind speed, rim-seal gap area, liquid level, and so forth) 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 hour after obtaining steady readings. In any event, a test shall not be considered steady until a minimum of 4 hours have elapsed. Thus, the absolute minimum test duration would be 5 hours (that is, 4 hours to establish steady conditions, then 1 hour of data recording). Typical test durations are apt to extend to 8 or 10 hours.

12 Calculation of Test Results

12.1 CALIBRATION CORRECTIONS

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

12.2 RIM-SEAL LOSS RATE

The rim-seal loss rate, L, of the test rim seal at any time during the course of a test shall be determined using Equation 3 from the simultaneous measurements of air volumetric flow rate, inlet hydrocarbon vapor concentration, outlet hydrocarbon vapor concentration, and hydrocarbon vapor density.

$$(T_d, °R) = (T_d, °F) + 459.67 \quad (1)$$

$$D_v = \frac{P_d, M_v}{R(T_d, °R)} \quad (2)$$

$$L = \left(\frac{1 \text{ volume fraction}}{10^6 \text{ ppmv}}\right)\left(\frac{60 \text{ min.}}{1 \text{ hour}}\right) Q_a\, D_v\, (C_o - C_i) \quad (3)$$

Where:

L = rim-seal loss rate (lb/hr);
Q_a = volumetric flow rate of the outlet air at actual conditions (acfm);
C_o = concentration of hydrocarbon vapor in the test chamber outlet air (ppmv);
C_i = concentration of hydrocarbon vapor in the test chamber inlet air (ppmv);
D_v = density of hydrocarbon vapor at the conditions of the test chamber outlet air (lb/ft^3);
P_d = static pressure in the outlet duct at the air flow rate sensor (psia);
M_v = molecular weight of test liquid vapor (lb/lb-mole);
R = universal gas constant (10.73; ft^3 psia/lb-mole °R); and
T_d = temperature of the air in the outlet duct at the air flow rate sensor (°R).

The evaporative loss rate that is to be used in determining the rim-seal loss factor shall be the mean of the loss rates measured during a test period of at least 1 hour duration following the establishment of a steady-state evaporative loss rate. The variance of the loss rate over the steady-state test period shall be determined, along with the uncertainty, based on a 95 percent confidence limit.

12.3 VAPOR PRESSURE FUNCTION

The vapor pressure function, P^*, as described in API Publications 2517 [7] and 2519 [11] and in the API *Manual of Petroleum Measurement Standards,* Chapter 19.2 [12], shall be determined from the mean of the measurements of test liquid temperature (T_l °F) and the mean of the measurements of atmospheric pressure, P_a, recorded during the steady-state test period using Equations 4, 5, and 6.

$$(T_l, °R) = (T_l, °F) + 459.67 \quad (4)$$

$$P = \exp\left[A_P - \frac{B_P}{(T_l, °R)}\right] \quad (5)$$

$$P^* = \frac{(P/P_a)}{[1 + [1 - (P/P_a)]^{0.5}]^2} \quad (6)$$

Where:

P_a = mean atmospheric pressure in the test room during the test period (psia);
A_p = 13.824 (dimensionless) for n-hexane; and
B_p = 6,907.2 (°R) for n-hexane.

The value of the vapor pressure constants, A_p and B_p, for isohexane depend on the actual test liquid composition.

12.4 RIM-SEAL LOSS FACTOR

The rim-seal loss factor, K_r, for each test shall be calculated at each level of wind speed from the rim-seal loss rate, L, and the vapor pressure function, P^*, using Equations 7 and 8.

$$L_r = (L, \text{lb/hr})(24 \text{ hr/day})(365.25 \text{ day/yr}) \quad (7)$$

$$K_r = \frac{(3.1416)\,L_r}{(L_s\ P^*\,M_v\,K_c)} \quad (8)$$

Where:

L_r = rim-seal loss rate (lb/yr);
L_s = length of the test rim seal (ft);
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 isohexane.

12.5 UNCERTAINTY ANALYSIS

Determine the uncertainty in the calculated rim-seal loss factor, K_r, by using the procedure described in Appendix A, Uncertainty Analysis.

13 Report of Test Results

13.1 REPORT

The report of a laboratory test to determine the rim-seal loss factor of a test rim seal shall include:

a. Name and location of the laboratory.
b. Description and drawings of the test apparatus.
c. Name and location of the test rim seal manufacturer.
d. Reid vapor pressure of the test liquid, as required in 7.9.
e. Description and drawings of the test rim seal, as required in 11.3.1.
f. Description of the method of joining and sealing the ends of the test rim seal to the end walls of the test chamber, as required in 7.8.
g. Description and calibration data for the instruments, as required in 11.3.2.
h. Description of the wind speed calibration of the test chamber, as outlined in Appendix B.
i. Test data, as required in 11.3.3.
j. Results of calculations, as outlined in 12.
k. Results of the uncertainty analysis, as outlined in Appendix A.
l. Results of the loss factor equation determination, as outlined in Appendix C.

13.2 DATA CURVES

Each calculated value of the rim-seal loss rate shall be presented on a time-based loss rate curve, which shall include each of the individual 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 loss rate values, as described in 12.2. A typical loss rate curve is shown in Figure 4.

Accompanying curves and tables shall be included that show:

a. Air volumetric flow rate.
b. Test chamber pressure rise.
c. Hydrocarbon vapor concentrations.
d. Temperatures of the test liquid, the air in the outlet duct, and the air in the test room.
e. Atmospheric pressure.

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, rim-seal loss rate, air volumetric flow rate, and so forth) as the ordinate.

13.2.2 Display

Data 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 rim seal description, the test rim-seal gap area (and any other relevant seal parameter), the wind speed, and the names of the rim seal manufacturer and the test laboratory.

13.3 RIM-SEAL LOSS FACTOR GRAPH

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

13.3.1 Coordinates

Rim-seal loss factor graphs shall be drawn with wind speed as the abscissa and rim-seal loss factor as the ordinate.

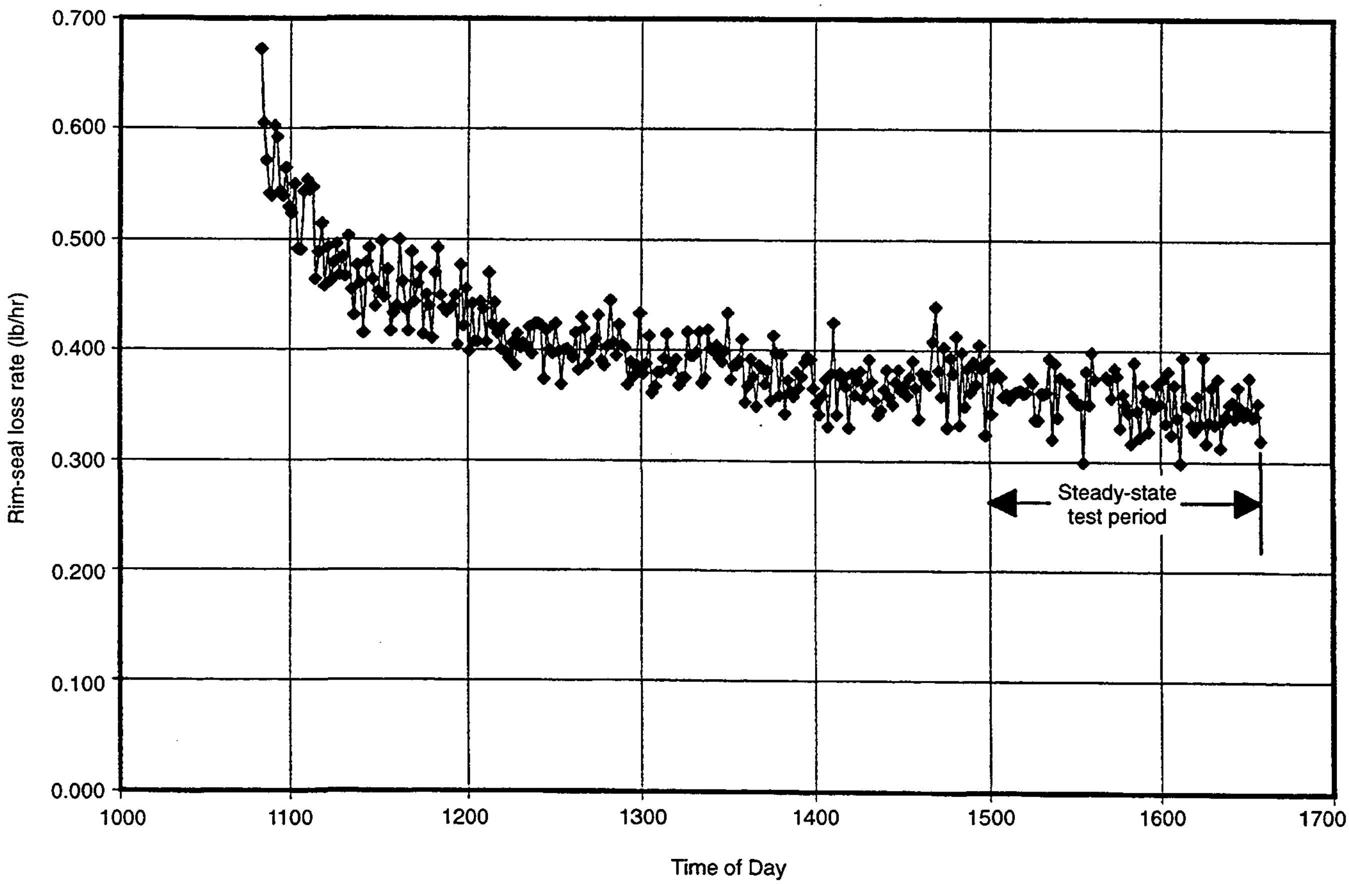
13.3.2 Display

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

The curve of the loss factor equation, determined in accordance with Appendix C, shall also be displayed. The rim-seal loss factor graph shall list the test rim seal description and the names of the manufacturer and test laboratory.

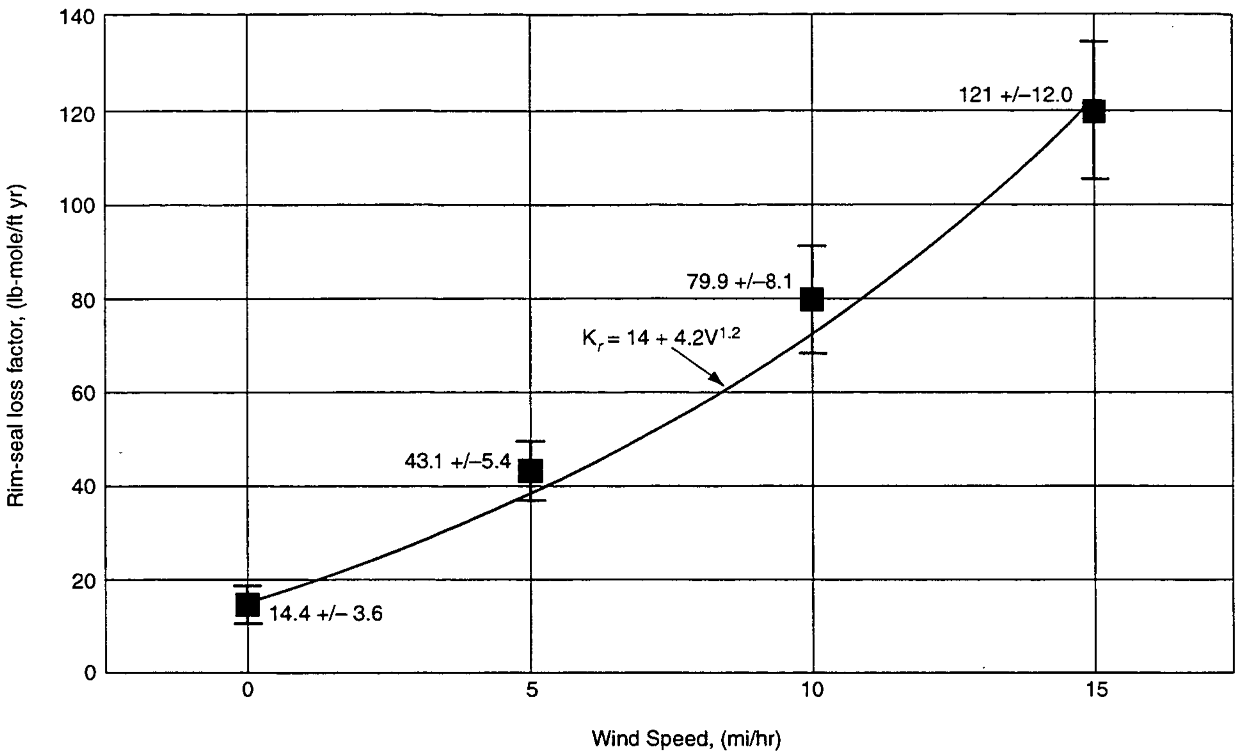
14 Precision and Bias

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



Test Rim-Seal Description:	Mechanical-Shoe Primary Seal
Rim-Seal Gap Area:	1.00 in.^{2}/foot diameter
Wind Speed:	8.61 ± 0.43 mi/hr
Mean Rim-Seal Loss Rate:	0.35200 lb/hr
Standard Deviation:	6.56% of the mean value
95% Confidence Limit:	±0.046182 lb/hr
Test Number:	1
Rim Seal Manufacturer:	Seals-R-Us
Test Laboratory:	Tests-R-Us

Figure 4—Typical Data Curve (Rim-Seal Loss Rate)



Test Rim Seal Description:	Mechanical-Shoe Primary Seal
Rim Seal Gap Area:	1.00 in.^{2}/foot diameter
Rim Seal Manufacturer:	Seals-R-Us
Test Laboratory:	Tests-R-Us

Figure 5—Typical Rim-Seal Loss Factor Graph

APPENDIX A—UNCERTAINTY ANALYSIS

A.1 General

Loss factor determinations are always subject to some level of uncertainty as a 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 rim-seal loss factor, K_r, that results from the effects of the individual measurement uncertainties. The results 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:

$$E_X = U_X/X \qquad \text{(A-1)}$$

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.

$$X \pm U_x \qquad \text{(A-2)}$$

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	Units
F	Defined by Equation A-7	dimensionless
R_p	Ratio of vapor pressure to atmospheric pressure	dimensionless
	Per Unit Uncertainty Of:	
E_{A_p}	Constant in the vapor pressure equation	dimensionless
E_{B_p}	Constant in the vapor pressure equation	dimensionless
E_{K_c}	Product factor	dimensionless
E_{K_r}	Rim-seal loss factor	dimensionless
E_L	Rim-seal loss rate	dimensionless
E_{L_s}	Length of rim seal	dimensionless
E_{M_v}	Molecular weight of stock vapor	dimensionless
E_P	Vapor pressure of the stock	dimensionless
E_{P*}	Vapor pressure function	dimensionless
E_{P_a}	Atmospheric pressure	dimensionless
E_{R_p}	Ratio of vapor pressure to atmospheric pressure	dimensionless
E_T	Stock liquid temperature	dimensionless
E_V	Wind speed	dimensionless
	Absolute Uncertainty Of:	
U_{A_p}	Constant in the vapor pressure equation	dimensionless
U_{B_p}	Constant in the vapor pressure equation	°R
U_{K_c}	Product factor	dimensionless
U_{K_r}	Rim-seal loss factor	lb-mole/ft yr
U_L	Rim-seal loss rate	lb/hr
U_{L_s}	Length of rim seal	ft
U_{M_v}	Molecular weight of stock vapor	lb/lb-mole
U_P	Vapor pressure of the stock	psia
U_{P*}	Vapor pressure function	dimensionless
U_{P_a}	Atmospheric pressure	psia
U_{R_p}	Ratio of vapor pressure to atmospheric pressure	dimensionless
U_T	Stock liquid temperature	°F or °R
U_V	Wind speed	mi/hr

A.4 Uncertainty Formulas

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

A.4.1 Uncertainty in the Vapor Pressure

The per unit uncertainty in the vapor pressure, E_P, may be calculated from Equation A-3.

$$E_P = [A_p^2\, E_{A_p}^2 + (B_p / T_l)^2 (E_{B_p}^2 + E_T^2)]^{0.5} \qquad \text{(A-3)}$$

The per unit uncertainties of the constants in the vapor pressure equations, E_{A_p} and E_{B_p}, depend upon the purity of the test liquid.

A sample of the test liquid shall be tested to determine the Reid vapor pressure of the mixture, in accordance with ASTM D323. That vapor pressure determination shall also include a value for the per unit uncertainty in the vapor pressure, E_P.

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

A.4.2 Uncertainty in the Vapor Pressure Function

In determining the per unit uncertainty of 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-4.

$$R_p = P / P_a \quad \text{(A-4)}$$

The per unit uncertainty in R_p may be calculated from Equation A-5.

$$E_{R_p} = [E_P^2 + E_{P_a}^2]^{0.5} \quad \text{(A-5)}$$

The atmospheric pressure, P_a, may vary during the course of a test. The atmospheric pressure used in the loss factor determination is based on the mean of the measurements of atmospheric pressure recorded during the 1-hour steady-state test 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 test period. It should be noted, however, that the per unit uncertainty in the mean atmospheric pressure, E_{P_a}, is typically small in comparison to the per unit uncertainty in the mean stock vapor pressure, E_p.

The per unit uncertainty of the vapor pressure function, E_{P^*}, may be calculated from Equation A-6.

$$E_{p^*} = FE_{Rp} \quad \text{(A-6)}$$

Where:

$$F = \left[\frac{1 + (1 - R_p)^{0.5}}{1 + (1 - R_p)^{0.5} - R_p}\right] \quad \text{(A-7)}$$

A.4.3 Uncertainty in the Rim-Seal Loss Factor

The per unit uncertainty in the rim-seal loss factor, E_{K_r}, may be calculated from Equation A-8.

$$E_{K_r} = [E_L^2 + E_{L_s}^2 + E_{P^*}^2 + E_{M_v}^2 + E_{K_c}^2]^{0.5} \quad \text{(A-8)}$$

The per unit uncertainty in the rim-seal loss rate shall include any known bias errors in the calibration of the instrumentation used to measure the air volumetric flow rate, hydrocarbon concentrations and outlet duct air temperature and pressure, as well as random errors resulting from variations in the rim-seal loss rate during the minimum 1-hour steady-state test period.

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

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

A.5 Example Uncertainty Analysis

This section presents an example uncertainty analysis for a rim-seal loss factor test. Table A-1 summarizes the results of the uncertainty analysis.

A.5.1 Uncertainty in the Vapor Pressure

Calculate P:

A_P = 13.940 (dimensionless; from the test data)
B_P = 6,698.0°R (from the test data)
T_l = 525.27°R (from the test data).

From Equation 2:

$$\begin{aligned} P &= \exp [A_p - (B_p/T_l)] \\ &= \exp [(13.940) - (6{,}698.0/525.27)] \\ &= 3.2820 \text{ psia.} \end{aligned}$$

Calculate E_P:

$E_{A_p} = 1.0000 \times 10^{-3}$ (from the test data)

$E_{B_p} = 1.0000 \times 10^{-3}$ (from the test data)

$E_{T_l} = 5.7113 \times 10^{-3}$ (from the test data).

From Equation A-3:

$$\begin{aligned} E_P &= [A_P^2 E_{A_p}^2 + (B_p / T_l)^2 (E_{B_p}^2 + E_{T_l}^2)]^{0.5} \\ &= [(13.940)^2 (1.0000 \times 10^{-3})^2 + (6{,}698.0 / 525.27)^2 \\ &\quad ((1.0000 \times 10^{-3})^2 + (5.7113 \times 10^{-3})^2)]^{0.5} \\ &= 7.5238 \times 10^{-2} \end{aligned}$$

Calculate U_P:

$$\begin{aligned} U_P &= E_P P \\ &= (7.5238 \times 10^{-2})(3.2820) \\ &= 0.24693 \text{ psia} \end{aligned}$$

Table A-1—Summary of Example Uncertainty Analysis Results

Description	Symbol	Units	Value
Given test data:			
Rim-seal loss rate	L	lb/hr	0.35200
	U_L	lb/hr	4.6182×10^{-2}
	E_L	dimensionless	0.13120
Stock liquid temperature	T_l	°F	65.600
	T_l	°R	525.27
	U_{T_l}	°R	3.0000
	E_{T_l}	dimensionless	5.7113×10^{-3}
Vapor pressure constant	A_p	dimensionless	13.940
	U_{A_p}	dimensionless	1.3940×10^{-2}
	E_{A_p}	dimensionless	1.0000×10^{-3}
Vapor pressure constant	B_p	°R	6,698.0
	U_{B_p}	°R	6.6980
	E_{B_p}	dimensionless	1.0000×10^{-3}
Atmospheric pressure	P_a	psia	14.587
	U_{P_a}	psia	0.43761
	E_{P_a}	dimensionless	3.0000×10^{-2}
Vapor molecular weight	M_v	lb/lb-mole	85.970
	U_{M_v}	lb/lb-mole	8.5970×10^{-2}
	E_{M_v}	dimensionless	1.0000×10^{-3}
Rim seal length	L_S	feet	26.350
	U_{L_s}	feet	4.1667×10^{-2}
	E_{L_s}	dimensionless	1.5813×10^{-3}
Product factor	K_c	dimensionless	1.0000
	U_{K_c}	dimensionless	0
	E_{K_c}	dimensionless	0
Wind speed	V	mi/hr	8.6100
	U_V	mi/hr	0.43050
	E_V	dimensionless	5.0000×10^{-2}

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

Description	Symbol	Units	Value
Calculated test results:			
Vapor pressure	P	psia	3.2820
	U_P	psia	0.24693
	E_P	dimensionless	7.5238×10^{-2}
Ratio of vapor pressure to atmospheric pressure	R_p	dimensionless	0.22499
	U_{R_p}	dimensionless	1.8224×10^{-2}
	E_{R_p}	dimensionless	8.0998×10^{-2}
Vapor pressure function	$P*$	dimensionless	6.3634×10^{-2}
	U_{P*}	dimensionless	5.8547×10^{-3}
	E_{P*}	dimensionless	9.2006×10^{-2}
Rim-seal loss factor	K_r	lb-mole/ft yr	67.248
	U_{K_r}	lb-mole/ft yr	10.777
	E_{K_r}	dimensionless	0.16026

A.5.2 Uncertainty in the Ratio of Vapor Pressure to Atmospheric Pressure

Calculate R_p:

$$P = 3.2820 \text{ psia (from A.5.1)}$$
$$P_a = 14.587 \text{ psia (from the test data).}$$

From Equation A-4:

$$R_p = P/P_a = (3.2820)/(14.587) = 0.22499$$

Calculate E_{R_p}:

$$E_p = 7.5238 \times 10^{-2} \text{ (from A.5.1)}$$

$$E_{P_a} = 3.0000 \times 10^{-2} \text{ (from the test data).}$$

From Equation A-5:

$$E_{R_p} = \left[E_p^2 + E_{P_a}^2\right]^{0.5}$$

$$= [(7.5238 \times 10^{-2})^2 + (3.0000 \times 10^{-2})^2]^{0.5}$$
$$= 8.0998 \times 10^{-2}$$

Calculate U_{R_p}:

$$U_{R_p} = E_{R_p} R_p$$

$$= (8.0998 \times 10^{-2})(0.22499)$$
$$= 1.8224 \times 10^{-2}$$

A.5.3 Uncertainty in the Vapor Pressure Function

Calculate $P*$:

$$R_p = 0.22499 \text{ (from A.5.2).}$$

From Equation 6:

$$P* = R_p/[1 + (1 - R_p)^{0.5}]^2$$
$$= (0.22499)/[1 + (1 - 0.22499)^{0.5}]^2$$
$$= 6.3634 \times 10^{-2}$$

Calculate E_{P*}:

$$E_{R_p} = 8.0998 \times 10^{-2} \text{ (from A.5.2).}$$

From Equation A-7:

$$F = \left[\frac{1 + (1 - R_p)^{0.5}}{1 + (1 - R_p)^{0.5} - R_p}\right]$$

$$= \left[\frac{1 + (1 - 0.22499)^{0.5}}{1 + (1 - 0.22499)^{0.5} - (0.22499)}\right]$$

$$= 1.1359$$

From Equation A-6:

$$E_{p*} = FE_{R_p}$$

$= (1.1359)(8.0998 \times 10^{-2})$

$= 9.2006 \times 10^{-2}$

Calculate U_{P*}:

$U_{P*} = E_{P*}P*$

$= (9.2006 \times 10^{-2})(6.3634 \times 10^{-2})$

$= 5.8547 \times 10^{-3}$

A.5.4 Uncertainty in the Rim-Seal Loss Factor

Calculate K_r:

L	$= 0.35200$ lb/hr	(from the test data)
$P*$	$= 6.3634 \times 10^{-2}$	(from A.5.3)
M_v	$= 85.970$ lb/lb-mole	(from the test data)
L_s	$= 26.350$ ft	(from the test data)
K_c	$= 1.0000$	(from the test data).

From Equations 7 and 8:

$K_r = [(3.1416)(24)(365.25)L]/(L_s P^* M_v K_c)$

$= [(3.1416)(24)(365.25)(0.35200)]/[(26.350)(6.3634 \times 10^{-2})(85.970)(1.0000)]$

$= 67.248$ lb-mole/ft yr

Calculate E_{K_r}:

E_L	$= 0.13120$	(from the test data)
E_{p*}	$= 9.2006 \times 10^{-2}$	(from A.5.3)
E_{M_v}	$= 1.0000 \times 10^{-3}$	(from the test data)
E_{L_s}	$= 1.5813 \times 10^{-3}$	(from the test data)
E_{K_c}	$= 0$	(from the test data).

From Equation A-8:

$$E_{K_r} = [E_L^2 + E_{L_s}^2 + E_{P*}^2 + E_{M_v}^2 + E_{K_c}^2]^{0.5}$$

$$E_{K_r} = [(0.13120)^2 + (1.5813 \times 10^{-3})^2 + (9.2006 \times 10^{-2})^2 + (1.0000 \times 10^{-3})^2 + (0)^2]^{0.5}$$

$= 0.16026$

Calculate U_{K_r}:

$U_{K_r} = E_{K_r}K_r$

$= (0.16026)(67.248)$

$= 10.777$ lb-mole/ft yr

Summary:

The rim-seal loss factor, K_r, that resulted from the test data of this example can be stated as follows:

$K_r = 67.248 \pm 10.777$ lb-mole/ft yr,

at a wind speed of:

$V = 8.6100 \pm 0.4305$ mph (from the test data).

APPENDIX B—WIND SPEED CALIBRATION

B.1 General

Appendix B describes the method of determining the wind speed calibration of the test chamber. The wind speed calibration establishes the relationship between the air flow rate through the test chamber and the corresponding ambient wind speed at the site of an external floating-roof tank. The wind speed calibration also establishes the air flow rate through the test chamber that represents an internal floating-roof tank.

The wind speed calibration of the test chamber shall be repeated every 6 months.

B.2 Nomenclature

The nomenclature used in Appendix B is listed in the following table.

Symbol	Description	Units
C_p	Pressure coefficient above the rim seal	dimensionless
C_{pl}	Pressure coefficient above the rim seal on the leeward side of an external floating roof	dimensionless
C_{pw}	Pressure coefficient above the rim seal on the windward side of an external floating roof	dimensionless
ΔC_p	Pressure coefficient difference above the rim seal between the leeward and windward sides of an external floating roof	dimensionless
F	Correlation constant in Equation B.1	$\left[\frac{in.\ water}{(ft^3/min)^2}\right]$
g_c	Gravitational constant	lb ft/lbf sec^2
P_s	Ambient pressure above the rim seal	lbf/ft^2
P_{sl}	Ambient pressure above the rim seal on the leeward side of an external floating roof	lbf/ft^2
P_{sw}	Ambient pressure above the rim seal on the windward side of an external floating roof	lbf/ft^2
ΔP_s	Ambient pressure difference above the rim seal between the leeward and windward sides of an external floating roof	lbf/ft^2 or in. water
Q	Air flow rate through the test chamber	ft^3/min
V	Ambient wind speed at the tank site	ft/sec or mi/hr
ρ	Density of ambient air	lb/ft^3

B.3 Test Chamber Air Flow Rate Tests

As part of the wind speed calibration procedure, a series of tests shall be performed where the air static pressure above the test rim seal is measured both at the test chamber inlet, P_{sw}, which represents the windward side of an external floating roof, and at the test chamber outlet, P_{sl}, which represents the leeward side of an external floating roof. These pressure measurements shall be made at locations that are within 6 inches, both horizontally and vertically, of the floating-roof rim in the test chamber.

The pressure difference, ΔP_s, shall be measured for at least five different test chamber air flow rates, Q. A correlation shall be performed of the values of measured pressure difference, ΔP_s, and measured air flow rate, Q, using Equation B-1.

$$\Delta P_s = FQ^2 \qquad \text{(B-1)}$$

where ΔP_s has units of inches water and Q has units of ft^3/min.

B.4 Wind Speed Calibration for an External Floating Roof

Evaporative losses from rim seals on external floating roofs have been found to depend upon the ambient pressure variation around the floating-roof rim. This pressure variation is produced by ambient wind flowing over the external floating roof. Higher pressures are produced on the leeward side than on the windward side of the floating roof. This pressure variation causes ambient air to flow downward through gaps in the rim seal on the leeward side of floating roof; to flow circumferentially around the rim vapor space below the rim seal where it mixes with product vapors; and to flow upward through gaps in the rim seal on the windward side of the floating roof where it results in evaporative loss.

Since the rim-seal loss from an external floating roof is dependent upon the ambient pressure variation around the rim, the wind speed calibration of the test chamber is based on creating a similar pressure variation on the test rim seal.

Wind tunnel tests on model external floating-roof tanks have established the pressure coefficient, C_p, variation around the rim of the floating roof. The pressure coefficient, C_p, is defined by Equation B-2.

$$C_p = \frac{P_s}{\left[\frac{\rho V^2}{2g_c}\right]} \qquad \text{(B-2)}$$

The pressure coefficient difference, ΔC_p, is the difference between the pressure coefficient on the leeward side of the floating roof, C_{pl}, and the pressure coefficient on the windward side of the floating roof, C_{pw}, as shown by Equation B-3.

$$\Delta C_p = (C_{pl} - C_{pw}) \qquad \text{(B-3)}$$

Substituting Equation B-2 into Equation B-3, we obtain a relationship between the pressure coefficient difference, ΔC_p, and the ambient pressure difference, ΔP_s, as shown by Equation B-4.

$$\Delta C_p = \frac{\Delta P_s}{\left[\frac{\rho V^2}{2 g_c}\right]} \quad \text{(B-4)}$$

Where:

$$\Delta P_s = (P_{sl} - P_{sw}) \quad \text{(B-5)}$$

Equation B-4 may be rearranged to form the relationship between the pressure difference, ΔP_s, and the ambient windspeed, V, shown by Equation B-6.

$$\Delta P_s = \Delta C_p \left(\frac{\rho V^2}{2 g_c}\right) \quad \text{(B-6)}$$

Wind tunnel tests on model external floating-roof tanks have established a value of 1.0 for the pressure coefficient difference, ΔC_p. This value is independent of the tank diameter and the floating-roof level.

The following values are used for ΔC_p, ρ and g_c:

$$\Delta C_p = 1.0 \quad \text{(B-7)}$$

$$\rho = 0.07634 \text{ lb/ft}^3 \quad \text{(B-8)}$$

$$g_c = 32.173 \text{ lb ft/lbf sec}^2 \quad \text{(B-9)}$$

Using the above values in Equation B-6 results in Equation B-10.

$$\Delta P_s = 0.001186 V^2 \quad \text{(B-10)}$$

where ΔP_s has units of lbf/ft^2 and V has units of ft/sec.

Equation B-10 can be converted to Equation B-11 for more convenient use with the air concentration test apparatus.

$$\Delta P_s = 0.0004910 V^2 \quad \text{(B-11)}$$

where ΔP_s has units of inches water and V has units of mph.

In the test chamber, the inlet side represents the windward side of a floating roof and the outlet side represents the leeward side of a floating roof. Thus, the test chamber represents one half of the perimeter of a floating roof.

Equation B-10 may be substituted into Equation B-1 to obtain Equation B-12, which is the resulting wind speed calibration equation of the test chamber for conditions simulating ambient wind on the rim seal of an external floating roof.

$$V = 45.13\, F^{1/2} Q \quad \text{(B-12)}$$

where V has units of mph and Q has units of ft^3/min.

Example:

For example, one series of test chamber air flow rate tests resulted in a correlation constant, F, of 5.19×10^{-9} inches water/(ft^3/min)^2. Using this value for the correlation constant, Equation B-12 becomes Equation B-13.

$$V = 0.003251 Q \quad \text{(B-13)}$$

B.5 Wind Speed Calibration for an Internal Floating Roof

Based on available data, the air flow rate, Q, corresponding to an ambient wind speed of 0.5 mi/hr for an external floating roof is the air flow rate that shall be used to represent an internal floating roof. Substituting a wind speed, V, of 0.5 mph into Equation B-12 results in Equation B-14, which is the wind speed calibration equation for conditions simulating an internal floating roof.

$$Q = 0.01108/F^{1/2} \quad \text{(B-14)}$$

Rim-seal loss factor tests that are performed under the air flow rate conditions described here are referred to as zero wind speed tests in C.3.

Example:

For example, one series of test chamber air flow rate tests resulted in a correlation constant of 5.19×10^{-9} inches water/(ft^3/min).^{2} Using this value for the correlation constant, Equation B-14 becomes Equation B-15.

$$Q = 153.8 \text{ ft}^3\text{/min} \quad \text{(B-15)}$$

APPENDIX C— DETERMINATION OF LOSS FACTOR EQUATION

C.1 General

Appendix C provides the method for determining the loss factor equation from the test data for a particular rim seal. The loss factor equation is determined by fitting a curve to the plot of the loss factors (K_r) calculated for each test versus wind speed (V).

This appendix describes a calculation method that shall be used to determine the loss factor equation. The result of these calculations shall be included in the report of test results.

C.2 Nomenclature

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

Symbol	Description	Units
K_{ra}	Coefficient in the loss factor equation	lb-mole/ft yr
K_{rb}	Coefficient in the loss factor equation	lb-mole/(mph)^{n}ft yr
n	Exponent in the loss factor equation	dimensionless
E_{net}	Defined by Equation C-6	lb-mole/ft yr

C.3 Loss Factor Equation

The loss factor equation is determined from the loss factors (K_r) that were calculated for each test and the corresponding measured levels of wind speed (V). A curve in the form of Equation C-1 is fit to these data.

$$K_r = K_{ra} + K_{rb}V^n \tag{C-1}$$

The curve of Equation C-1 shall be fit to the data by using a standard least squares regression procedure on a log-log scale, which requires that Equation C-1 first be transformed from an exponential to a linear form by the steps shown in Equations C-2, C-3, and C-4.

Subtract K_{ra} from each side of Equation C-1,

$$K_r - K_{ra} = K_{rb}\ V^n \tag{C-2}$$

Take the log of each side of Equation C-2,

$$\log(K_r - K_{ra}) = \log(K_{rb}V^n) \tag{C-3}$$

This may also be expressed as Equation C-4.

$$\log(K_r - K_{ra}) = \log(K_{rb}) + n\ \log\ (V) \tag{C-4}$$

Equation C-4 is a linear equation on a log-log scale and may be simplified as shown in Equation C-5.

$$\log(E_{net}) = \log(K_{rb}) + n\ \log(V) \tag{C-5}$$

Where:

$$E_{net} = K_r - K_{ra} \tag{C-6}$$

The coefficient K_{ra} is determined as the loss factor (K_r) calculated from one or more zero wind speed tests conducted at a wind speed of 0.5 mph, as discussed in 11.2 and B.5, or it may be calculated from one or more test conditions in accordance with API *Manual of Petroleum Measurement Standards,* Chapter 19.3, Part C, "Weight Loss Test Method, Rim-Seal Loss Factors for Internal Floating-Roof Tanks" [13]. If more than one zero wind speed test is conducted, then the mean of the loss factors from each zero wind speed test shall be calculated to determine K_{ra}.

A net emission level (E_{net}) is determined for each test conducted at a non-zero wind speed by subtracting the zero wind speed loss factor (K_{ra}) from the loss factor (K_r) that was calculated at each of the non-zero wind speeds.

The least squares regression is then used to fit the linear curve of Equation C-5 to the weighted database. The curve is fit to the log-transformed values of E_{net} and V, resulting in estimates of n and log (K_{rb}). The coefficient K_{rb} is then determined from Equation C-7.

$$K_{rb} = 10^{(\log(K_{rb}))} \tag{C-7}$$

The values of K_{ra}, K_{rb}, and n determined by this procedure are the constants in the loss factor equation for the tested rim seal.

C.4 Example Determination of Loss Factor Equation

This section presents an example determination of a rim-seal loss factor equation. Table C-1 lists the loss factors (K_r) calculated for each of the tests that are assumed to have been conducted in the example. Table C-2 summarizes the database for the least squares regression, and Table C-3 summarizes the results of the loss factor equation determination.

The coefficient K_{ra} is determined as the arithmetic mean of all loss factors at the nominal 0 mph wind speed level. The 0 mph wind speed level includes all tests at wind speeds at or below 0.5 mph (see 11.2 and B.5), and thus K_{ra} is the average of the loss factors from Tests 1 and 2, as shown in Equation C-8.

$$K_{ra} = (8.36 + 9.78)/2 \tag{C-8}$$

$$K_{ra} = 9.07 \text{ lb-mole/ft yr}$$

The net emissions level, E_{net}, shall be determined for each of the non-zero wind speed data points. The database is then compiled by taking the log of the wind speed (V) and the log of the net emission level (E_{net}) for each data point. These steps are summarized in Table C-2.

The data in Table C-2 is fit to a curve by a least squares regression, with the log transform of the net emission level ($\log(E_{net})$) as the dependent variable and the log transform of the wind speed (log (V)) as the independent variable. The estimates of n and log (K_{rb}) generated by the least squares regression are:

$n = 1.41,$
log (K_{rb}) = 0.597.

The coefficient K_{rb} is then determined from Equation C-7.

$$K_{rb} = 3.95 \text{ lb-mole/(mph)}^n \text{ ft yr}$$

The values for the loss factor equation constants K_{ra}, K_{rb} and n determined by this procedure are listed in Table C-3.

Table C-1—Example Loss Factors

Test No.	Nominal Wind Speed Level (mph)	Wind Speed (V) (mph)	Loss Factor (K_r) (lb-mole/ft yr)
1	0	0.421	8.36
2	0	0.350	9.78
3	5	4.91	47.2
4	10	9.36	97.1
5	10	10.2	112.0
6	10	10.1	109.0
7	15	14.6	189.0

Table C-2—Example Loss Factor Equation Database

Test No.	Nominal Wind Speed Level (mph)	Wind Speed (V) (mph)	log (V)	Loss Factor (K_r) $\left(\frac{\text{lb-mole}}{\text{ft yr}}\right)$	Loss Factor (K_{ra}) $\left(\frac{\text{lb-mole}}{\text{ft yr}}\right)$	E_{nct}	log (E_{nct})
3	5	4.91	0.691	47.2	9.07	38.1	1.581
4	10	9.36	0.971	97.1	9.07	88.0	1.944
5	10	10.2	1.009	112.0	9.07	103.0	2.013
6	10	10.1	1.004	109.0	9.07	99.9	2.000
7	15	14.6	1.164	189.0	9.07	180.0	2.255

Table C-3—Example Loss Factor Equation Constants

Coefficient (K_{ra}) (lb-mole/ft yr)	Coefficient (K_{rb}) (lb-mole/(mph)^n ft yr)	Exponent (n) (dimensionless)
9.07	3.95	1.41

APPENDIX D—METRIC UNITS

D.1 General

To convert the inch-pound 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 time is either the hour, designated hr, or the year, designated yr. The unit of temperature is the degree Celsius, designated °C, or the kelvin, designated *K*.

D.2 Velocity

The unit of velocity is the kilometer per hour, designated km/h.

D.3 Pressure

The unit of pressure is the kilopascal, designated kPa.

D.4 Loss Factors

The text employs the pound-mole per year, designated lb-mole/yr, as the unit of loss rate. The loss rate is determined as the product of the tank diameter, D, in units of feet, times the dimensionless coefficients P^* and K_c, times the loss factor, K_r, in units of lb-mole per foot year, designated lb-mole/ft yr, as described in API *Manual of Petroleum Measurement Standards,* Chapter 19.2 [12].

The equivalent SI unit for the loss rate is kilogram-mole per year, designated kmol/yr. The equivalent SI unit for the loss factor is kilogram-mole per meter year, designated kmol/m yr. As with the inch-pound units, the loss factor in kmole/m yr must be multiplied by the tank diameter, D, in units of meters and by the dimensionless coefficients P^* and K_c to obtain a loss rate in kmol/yr.

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