Manual of Petroleum Measurement Standards Chapter 19.3—Evaporative Loss Measurement

Part A—Wind Tunnel Test Method for the Measurement of Deck-Fitting Loss Factors for External Floating-Roof Tanks

FIRST EDITION, JUNE 1997
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FOREWORD

This standard provides rules for testing the deck fittings of external floating roofs under laboratory conditions to provide evaporative loss information. It was prepared by Task Group II of the API Environmental Technical Advisory Group (ETAG).

Testing programs conducted by API in 1984 and 1993 provided the information on which the current evaporative loss factors are based for common, generic types of external floating-roof deck fittings. These factors are published in the API *Manual of Petroleum Measurement Standards,* Chapter 19. 2, for use in estimating the evaporative loss of petroleum stocks from floating-roof tanks. These 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 loss factors for proprietary designs of individual manufacturers. By publishing a testing protocol, API is making the test method available to interested parties who wish to test particular deck fittings 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 the API *Manual of Petroleum Measurement Standards* (MPMS), Chapter 19.3, Part G.

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

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 the API MPMS, Chapter 19.3, Part F.

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

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Chapter 19.3—Evaporative Loss Measurement

PART A—WIND TUNNEL TEST METHOD FOR THE MEASUREMENT OF DECK-FITTING LOSS FACTORS FOR EXTERNAL FLOATING-ROOF TANKS

0 Introduction

The purpose of this standard is to establish a uniform method for use in measuring the evaporative loss factors for deck fittings of external floating-roof tanks. These loss factors are to be determined in terms of loss rate 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 deck fittings. Furthermore, equipment should not necessarily 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 loss factors for deck fittings of external floating-roof tanks. The test method involves measuring the weight loss of a test assembly over time. This standard specifies the test apparatus, the instruments, the test procedures, 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 References

The most recent editions of the following standards contain provisions that through reference in this text constitute provisions of this standard.

API

Manual of Petroleum Measurement Standards (MPMS)

Chapter 15, "Guidelines for the Use of the International Systems of Units (SI) in the Petroleum and Allied Industries"

Chapter 19.2, "Evaporative Loss From Floating-Roof Tanks"

Chapter 19.3, Part E, "Weight Loss Test Method for the Measurement of Deck-Fitting Loss Factors for Internal Floating-Roof Tanks"

Chapter 19.3, Part F, "Evaporative Loss Factor for Storage Tanks Certification Program"

Chapter 19.3, Part G, "Certified Loss Factor Testing Laboratory Registration"

Std 650 *Welded Steel Tanks for Oil Storage*

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*

3 Terminology

3.1 DEFINITIONS

For the purposes of this standard, the following definitions apply.

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

3.1.2 deck: That part of a floating roof which 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, which accommodate some functional or operational feature of the tank.

3.1.3 deck fitting: The device which 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.

3.1.4 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 API Standard 650.

[1]American Society for Testing and Materials, 100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428.

3.1.5 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.

3.1.6 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 preprogrammed to record data at prescribed intervals, to analyze the data that has been received, and to electronically store the results.

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

3.1.8 loss factor: An expression used to describe the evaporative loss rate characteristics of a given floating-roof device. In order to obtain the total standing-storage evaporative loss rate for a bulk liquid storage tank equipped with a floating roof, the sum of the evaporative loss factors for each of the individual devices 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, the stock vapor molecular weight, and a product factor.

3.1.9 product factor: A factor that describes the evaporative loss characteristics of a given liquid product. The product factor, the stock vapor molecular weight, and the vapor pressure function 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.

3.1.10 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.

3.1.11 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.

3.1.12 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 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*.

3.2.2 Loss Factors

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

The pound-mole per year units of the loss factor K_f 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 actual pound-moles of evaporative loss over time for a given liquid product. To convert the pound-mole per year units of the loss factor to a loss rate in terms of actual pound-moles per year, the loss factor K_f is multiplied by the dimensionless coefficients P^*, which is a function of the product vapor pressure, and K_c, the product factor.

A pound-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 convert the actual pound-moles per year loss rate to pounds per year of a given liquid product, the loss rate ($K_f \, P^* \, K_c$) is multiplied by the molecular weight of the product in its vapor phase, M_v, with molecular weight having units of pounds per pound-mole. Additional information may be found in the API MPMS, Chapter 19.2.

3.2.3 Pressure

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

3.2.4 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.

3.2.5 Velocity

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

3.3 NOMENCLATURE

Table 1 provides a description of the symbols and Units.

Table 1—Description of the Symbols and Units

Symbol	Description	Units
A_p	Constant in the vapor pressure equation	dimensionless
B_p	Constant in the vapor pressure equation	°R
K_c	Product factor	dimensionless
K_f	Deck-fitting loss factor	lb-mole/yr
L	Deck-fitting loss rate	lb/hr
L_f	Deck-fitting loss rate	lb/yr
M_v	Molecular weight of stock vapor	lb/lb-mole
P	True vapor pressure of the stock	psia
P_a	Atmospheric pressure	psia
P^*	Vapor pressure function	dimensionless
T	Stock liquid temperature	°R or °F
V	Wind speed	mi/hr

Note: See 3.2 for definitions of abbreviations for the units.

4 Summary of Test Method

The test method described in this standard uses a weight loss procedure to measure a rate of evaporative loss. A test assembly containing a volatile test liquid of known properties, such as normal hexane (n-hexane), is mounted on a scale and inserted into a wind tunnel. At a prescribed level of wind speed, the weight loss over time is measured. The data is then corrected for variations in temperature and atmospheric pressure during the period of the test, and a loss rate is determined. The loss rate is then factored for the properties of the test liquid in order to determine an evaporative loss factor for that test assembly at that level of wind speed.

5 Significance and Use

This test method establishes a procedure for measuring the evaporative loss factor for deck fittings of external floating–roof tanks. The testing is to be performed in a laboratory that has been approved by API for this purpose, in accordance with the API MPMS 19.3, Part G. The values determined by this method are to be evaluated in accordance with the API MPMS, Chapter 19.3, Part F, in order to assign an API-certified loss factor to the particular deck fitting tested. The laboratory approval procedure, the test method, and the evaluation method together constitute a procedure by which manufacturers of floating roofs may obtain API-certified loss factors for deck fittings 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 MPMS, Chapter 19.3, Part F.

6.2 LOW LOSS RATES

This test method is not valid for deck fittings that have a loss rate lower than the specified tolerance of the instruments, or lower than the observed range of drift of the scales.

7 Test Apparatus

7.1 TEST APPARATUS SCHEMATIC

Figures 1 and 2 are schematics of the test apparatus to be used to obtain the measurements necessary for developing a certified evaporative loss factor for a deck fitting of an external 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, except that the blower need not fit into the test room. 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.

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 in 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. The fan shall be positioned so as not to cause a disturbance that affects the scale weight readings.

7.2.4 Wind Tunnel Air

The air that is directed through the wind tunnel 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 wind tunnel shall be maintained within ±10°F of the temperature of the air in the test room.

7.3 WIND TUNNEL

The wind tunnel shall be a straight length of duct that air may be directed through by means of a blower, as illustrated in Figure 1. The duct should have a rectangular cross section so as to readily accommodate openings. There will typically be openings in the bottom to insert items to be tested, in the top for access hatches, and in the sides for viewing ports.

7.3.1 Wind Tunnel Size

The wind tunnel shall have a minimum cross section of 3 feet by 3 feet and shall be of sufficient length to accommodate measuring stations for performing tests and a suitable means for air flow control.

7.3.2 Measuring Stations

The wind tunnel may have one or more pairs of measuring stations, as shown in Figures 1 and 2. The measuring stations shall be arranged in series along the length of the wind tunnel. Each measuring station shall occupy a section of the wind tunnel at least 5 feet long. There shall be sufficient room beneath each measuring station for a scale. A frame shall be provided for supporting the scale that accommodates leveling the scale and adjusting its elevation. There shall be an opening in the bottom of the wind tunnel at each measuring station to allow the item to be tested to rest on the scale below. There may be an access hatch in the top of the wind tunnel to facilitate placement of the test items, and a window in the side for viewing the test item while the test is in progress.

7.3.3 Transformation Piece

A transformation piece shall be installed between the wind tunnel and the connection to the air blower. An access hatch may be installed in this transformation piece to facilitate inspection and cleaning of the air flow distribution mechanism.

7.3.4 Air Flow Control

The air flow pattern shall be controlled by an air flow distribution mechanism and air flow straighteners.

7.3.4.1 Air Flow Distribution Mechanism

An air flow distribution mechanism, such as a perforated plate or a screen, shall be installed in the wind tunnel to provide proper flow patterns. This distribution mechanism shall be located upstream of the measuring stations to insure a substantially uniform flow ahead of the measuring stations.

A velocity survey in the empty wind tunnel shall be performed at each measuring station at wind speeds of 5, 10, and 15 miles per hour. The maximum velocity recorded in this velocity survey at each measuring station shall not exceed the average velocity by more than 40 percent.

The wind tunnel shall have an access hatch immediately upstream of the air flow control section to allow inspection and cleaning of the distribution mechanism. This access hatch may be located in the transformation piece.

7.3.4.2 Air Flow Straighteners

Air flow straighteners shall be installed in the wind tunnel upstream of each pair of measuring stations. The upstream end of the upstream air flow straightener shall be located at least 6 inches downstream from the air flow distribution mechanism, as shown in Figures 1 and 2. The air flow straightener sections shall be at least 2 feet long and shall consist of air flow straightening devices, such as a bank of 2-inch diameter tubes.

7.4 AIR BLOWER

Air movement in the wind tunnel shall be provided by an air blower located at the upstream end of the wind tunnel. The air blower shall be capable of providing variable air flow rates corresponding to wind tunnel wind speeds ranging from 0 to 15 miles per hour. The air blower shall be capable of maintaining wind speed at a constant level within ±10 percent during a test period.

7.5 VIBRATION DAMPING

The transmission of vibrations to the scales 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 blower and the transformation piece of the wind tunnel.

7.6 TEST VESSELS

An item to be tested shall be mounted in the lid of a test vessel which shall rest on the scales. The test vessel, including its lid, shall be leaktight. The test vessel shall contain the test liquid.

7.6.1 Test Vessel Size

The size of the test vessel may vary to accommodate different sizes of test items. The test vessel shall be deep enough to allow the level of the test liquid surface to be within ±1 inch of a specified level. The level of the liquid surface is determined from the reference distance described in 8.3.

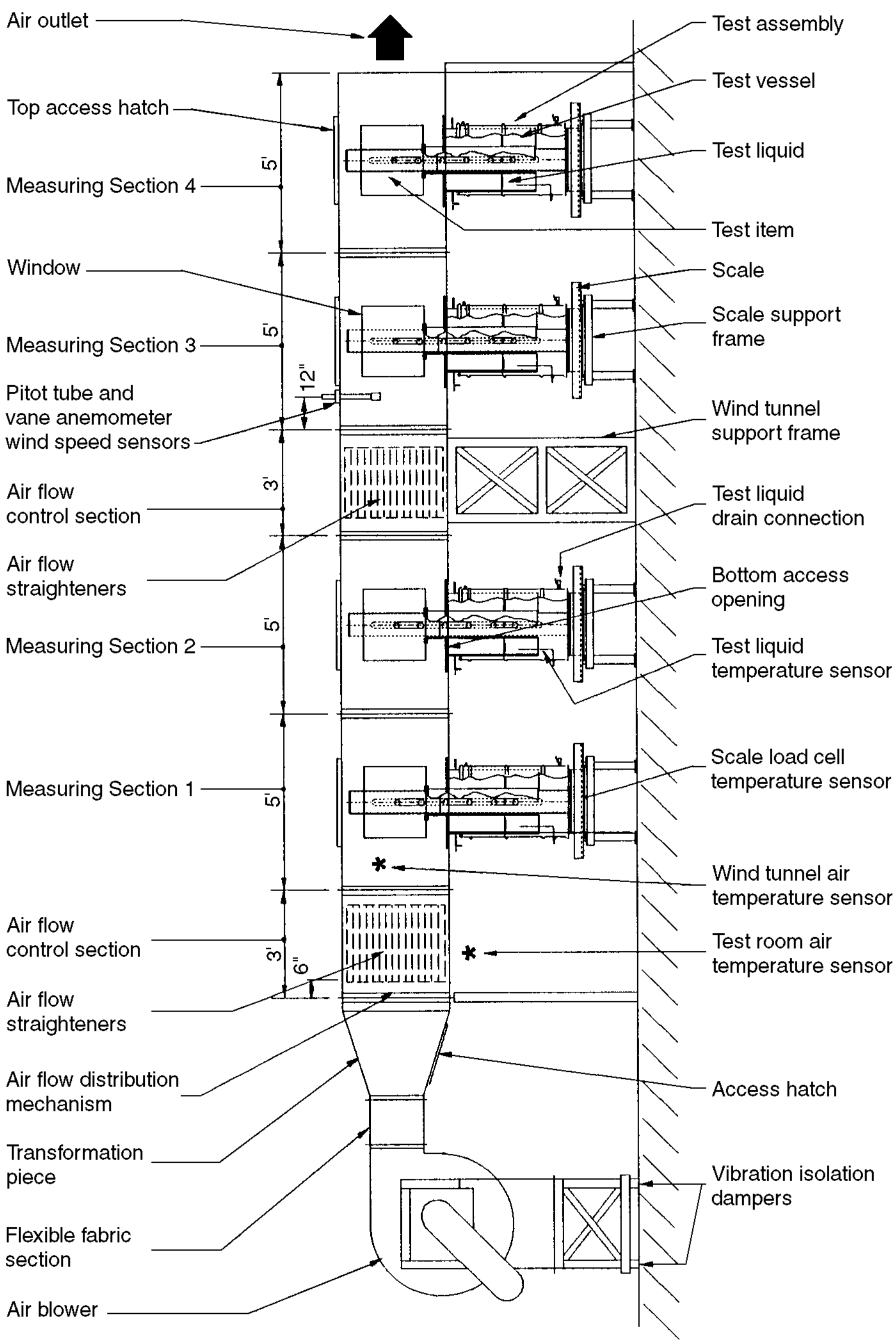


Figure 1—Elevation View of a Typical Wind Tunnel Test Facility

The test vessel shall be of sufficiently large diameter that the evaporative loss of test liquid that occurs during the test does not result in a change in the elevation of the test liquid surface of more than 1 inch during the course of the test.

Test items that exhibit very low loss rates will require scales that are capable of sensing smaller changes in weight than would be required for testing items with greater loss rates. This requirement may result in the use of a scale with a reduced load capacity for testing low loss rate items, thereby limiting the size of the test vessel. This may generally be accomplished by using a test vessel of a smaller diameter, in that the low loss rate will result in a minimal change in the level of the test liquid surface.

7.6.2 Test Liquid

The test liquid shall be n-hexane or isohexane, technical grade or better. During a test, the temperature of the test liquid

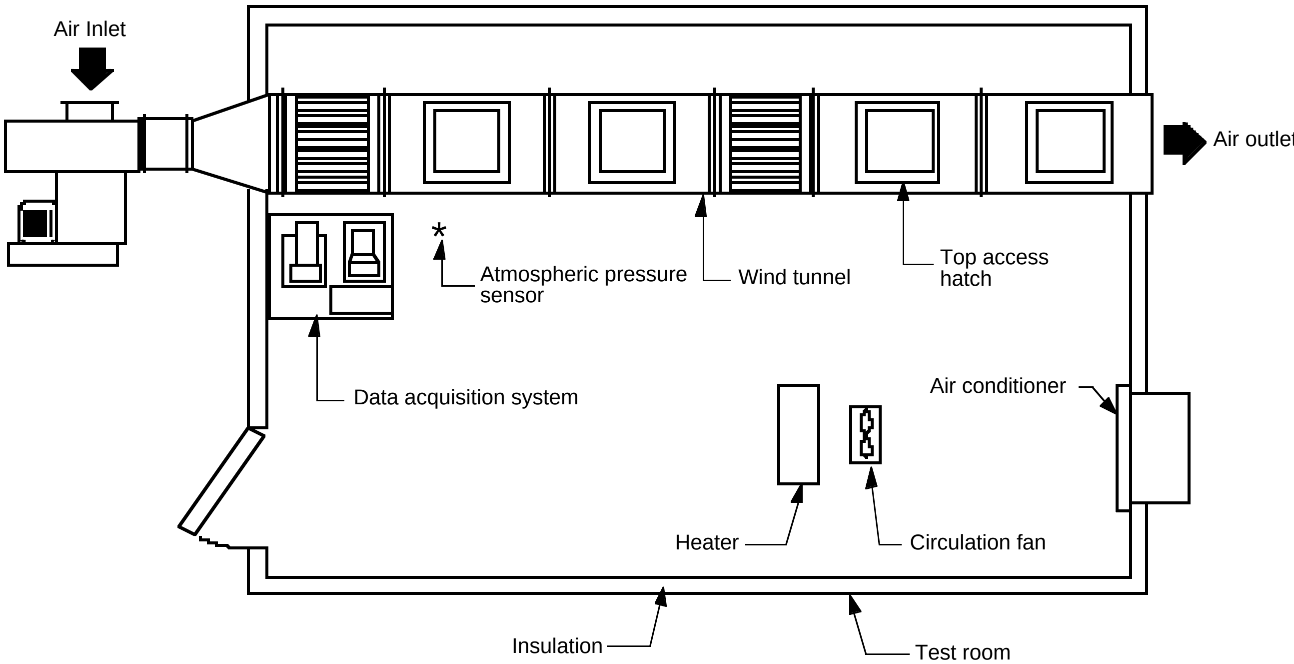


Figure 2—Plan View of a Typical Wind Tunnel Test Facility

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 D 323.

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 water at every exposed surface, inside and outside the test fitting, 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.

7.6.3 Emptying and Filling

All penetrations of or attachments to the test vessel, including those for emptying and filling, must be leak tight. A method of indicating the liquid level in the test vessel 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, but other methods that do not result in any loss of test liquid product or its vapors may also be used.

8 Test Item

8.1 TEST ITEM ASSEMBLY

The test items to be tested according to this test method are deck fittings for external floating-roof tanks. Items to be tested shall be full scale samples of the deck fittings, except as noted in 8.4. These samples shall be constructed according to the manufacturer's standard practice, and shall include all features typical to actual use. Figure 3 is a schematic of a representative test item assembly that includes the test item, test vessel, and test liquid.

8.2 FITTING ATTACHMENT

The fitting to be tested shall be attached to the lid of a test vessel in a manner similar to its attachment to the floating-roof deck in practice. Test fittings that normally extend into the liquid product on a storage tank shall be mounted on the test vessel in a manner that permits free flow of the test liquid from the test vessel into the bottom of the test fitting.

8.3 FITTING PLACEMENT

Fittings shall be centered in the width of the wind tunnel. When test fittings of differing sizes are to be tested at the same time, fittings with larger profiles shall be placed downstream of fittings with smaller profiles. As shown in Figure 3, the reference distance for vertical positioning of the test fitting shall be measured from the liquid surface to the top of the sleeve or well that penetrates the floating-roof deck.

The gap around a test fitting where it passes through the opening in the bottom of the wind tunnel shall be minimized by closing the space with an insert that has a cutout to match the shape of the fitting. The resulting gap in the insert around

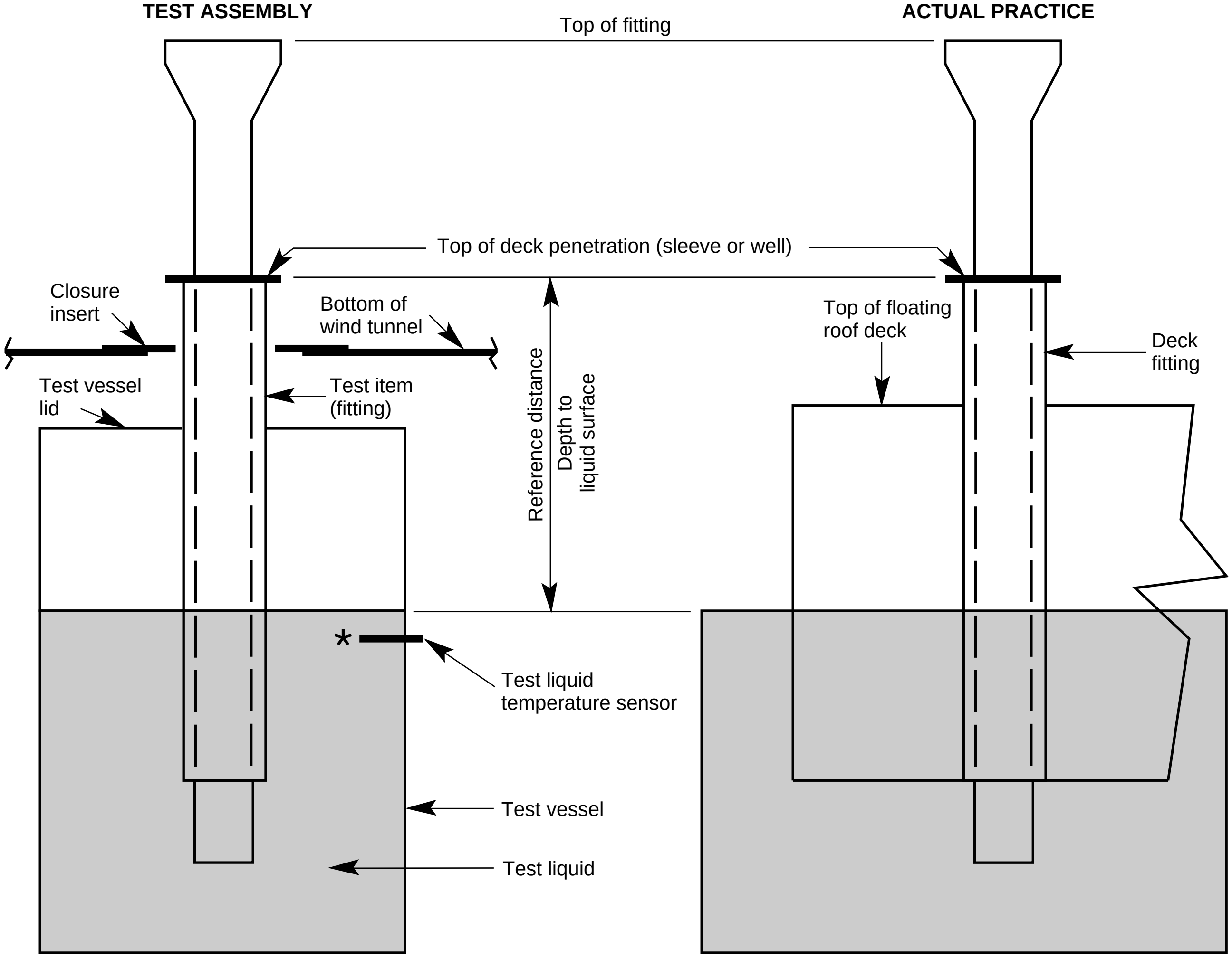


Figure 3—Test Assembly

the fitting shall not be greater than ½ inch. Extreme care shall be taken to avoid contact between the insert and the test fitting during a test.

8.4 TALL FITTINGS

Some fittings in practice accommodate the passage through the floating-roof deck of a device that extends to the top of the tank shell (for example, guidepoles). The test item assembly for these fittings shall include a portion of the extended feature projecting at least 2 feet above the bottom of the wind tunnel. The test fitting shall include the features typical of the deck fitting in actual practice.

8.5 FITTING ORIENTATION

Fittings that have features that are rectangular in plan shall be positioned such that the longest sides are parallel to the direction of the air flow. Fittings that have features that would result in their loss rate being significantly orientation dependent, such as slotted guidepole fittings, shall be tested at multiple orientations with the significant nonsymmetric feature at 0 degrees, 45 degrees, and 90 degrees to the direction of the air flow.

9 Preparation of Apparatus

9.1 TEST ASSEMBLY PLACEMENT

Place the test assembly on the scale so that the test fitting projects upward into the wind tunnel, as described in 8.3. Fill the test vessel with test liquid to the proper level, as described in 7.6.3.

9.2 AIR BLOWER STARTUP

Start the air blower and adjust its rotational speed to achieve the specified wind speed in the wind tunnel, as indicated by the pitot tube or vane anemometer.

9.3 STEADY STATE OPERATION

Start the data acquisition system and record the test assembly weight loss over a period of time until a steady rate of weight loss versus time is achieved. Following this initial start-up period during which the evaporation rate stabilizes, the subsequent test data recorded by the data acquisition system, as described in 11.2, shall constitute the record of test data that is to be used in calculating the evaporative loss factor.

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 2.

Procedures are also specified for certain steps of the measurement process which 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, thereby providing verification of the indicator as well as the sensor. Calibration standards shall be traceable to national measurement reference standards maintained by the 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. It shall have the capability to record sensor readings multiple times within a specified period of time, and then determine the mean and the standard deviation of these values. 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 WEIGHT MEASUREMENT

The weight of the test item assembly shall be sensed with high-precision scales, and the signal indicating the scale weight measurement shall be transmitted to the data acquisition system. The scales shall be capable of sensing weight changes of ±0.01 percent of the weight of the test assembly. Fittings that exhibit relatively low rates of evaporative loss may require the use of scales that are capable of sensing even smaller weight changes, or the length of a test period may need to be extended to permit adequate measurement of the weight change.

10.3.1 Scale Location

The scales shall be located outside of the wind tunnel, so as to minimize the effects of air stream interferences, as shown in Figure 1.

10.3.2 Scale Bias

Two procedures shall be undertaken to investigate the bias of the scales. First, the scales shall be calibrated. Secondly, dead weight effects (the variation over time in the observed value for a weight of known mass) shall be determined.

10.3.2.1 Scale Calibration

A scale shall be calibrated through its range of usage by measuring weights of known mass. The weights shall have certified accuracies of ±0.1 percent.

10.3.2.2 Dead Weight Effects

A scale shall be calibrated through its range of expected temperature variation by measuring a single weight of known mass for a period of 200 hours. The mass of the weight shall be within the range of usage for the test. The weight shall have a certified accuracy of ±0.1 percent.

10.3.2.2.1 The observed values for the weight of the known mass at varying scale temperatures shall be applied to the method presented in Appendix A to develop a correlation equation for the effect of temperature variation of the scale.

10.3.2.2.2 Drift effects, or the rate at which the observed value for the weight of the known mass varies over time, shall be determined.

10.3.2.2.3 If insufficient signal-to-noise ratio of the scale sensor output is observed, electronic-signal conditioning equipment may be installed. If used, the procedures for scale calibration, dead weight effects, temperature variation effects, and drift effects must be performed with the electronic-signal conditioning equipment installed.

10.3.3 Averaging Weight Readings

Since the testing conditions, as well as the power supply to the electronic instruments, are not strictly steady state, the weight indicated on any instrument may fluctuate with time. An individual weight reading shall therefore be taken as the average of at least 30 observations made during a period not greater than 5 minutes.

10.4 TEMPERATURE MEASUREMENT

Temperatures shall be sensed with thermocouples, and the signal 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.

10.4.1 Thermocouple Locations

Thermocouples shall be located so as to measure the temperature of the air in the wind tunnel, the bulk temperature of the test liquid at each measuring station, the temperature of the air in the test room, and the temperature of each scale load cell.

10.4.1.1 Wind Tunnel Temperature

A thermocouple shall be located at the first measuring station to measure the air temperature in the wind tunnel, as shown in Figure 1.

10.4.1.2 Test Liquid Temperature

A thermocouple shall be located within 3 inches below the test liquid surface in each test vessel to measure the bulk temperature of the test liquid, as shown in Figure 1.

10.4.1.3 Test Room Temperature

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

10.4.1.4 Scale Temperature

A thermocouple shall be located on the scale load cells to measure the temperature of each scale load cell, as shown in Figure 1.

10.4.2 Thermocouple Calibration

Each thermocouple shall be calibrated in accordance with ASTM E 220 using the temperature measurement system. All thermocouple calibrations shall be based on the temperature-electromotive force tables in ASTM E 230. The observed values shall not vary from the true values by more than ±0.5°F.

10.5 WIND SPEED MEASUREMENT

Wind speed shall be sensed with a vane anemometer and with a pitot tube equipped with an electronic pressure differential transducer. The signal from each sensor shall be transmitted to the data acquisition system. The vane anemometer shall be capable of sensing wind speed changes of 0.1 miles per hour and have a demonstrated accuracy of ±5 percent.

10.5.1 Wind Speed Sensor Location

The vane anemometer and the pitot tube shall each be located so as to measure the typical speed of the air in the wind tunnel. They shall not be located within 6 inches of the sides of the wind tunnel, so as to avoid boundary conditions of air flow. Each wind speed sensor shall be located at a position such that it is measuring a value that is within ±5 percent of the geometric average wind speed along the cross-section of the wind tunnel, based on a wind speed survey that is performed with an empty wind tunnel.

10.5.1.1 Vane Anemometer

The vane anemometer shall be located 1 foot downstream of the air flow straightener in either the first or third measuring station, as shown in Figure 1.

10.5.1.2 Pitot Tube

The pitot tube shall be located 1 foot downstream of the air flow straightener in either the first or third measuring station, as shown in Figure 1.

10.5.2 Wind Speed Sensor Calibration

Pitot tubes of the type described in Table 2 shall be considered primary instruments and need not be calibrated. The observed values from the vane anemometer shall not vary from the pitot tube readings by more than ±5 percent.

10.6 VOLTAGE MEASUREMENT

Voltage shall be measured with an electrical meter in the data acquisition system. The voltage supplied to the scale load cells shall be maintained within ±1 percent of the voltage used to calibrate the load cells.

10.7 ATMOSPHERIC PRESSURE MEASUREMENT

Atmospheric pressure shall be sensed with a pressure transducer, and the signal transmitted to the data acquisition system. The atmospheric pressure transducer shall be capable of sensing atmospheric pressure changes of ±0.01 pounds per square inch absolute with a demonstrated accuracy of ±0.05 pounds per square inch absolute.

10.7.1 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 2.

Table 2—Instrument Requirements

Variable To Be Measured	Instrument Type	Maximum Tolerable Error	Maximum Calibration Interval
Weight of the test apparatus	Scale	±0.1%	3 months
Time of the observation	Clock of the DAS	±0.1%	6 months
Wind speed	Vane anemometer Pitot tube	±5% NA	6 months NA
Temperature of the air in the wind tunnel	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 test room	Thermocouple	±0.5°F	6 months
Temperature of the scale or load cell	Thermocouple	±0.5°F	6 months
Voltage delivered by the power supply	Voltmeter of the DAS	±0.1%	6 months
Atmospheric pressure	Pressure transducer	±0.05 psia	6 months

10.7.2 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 pounds per square inch absolute.

11 Test Procedure

11.1 LEVELS OF WIND SPEED

11.1.1 Multiple Wind Speeds

Tests shall be conducted at multiple wind speed levels for each item tested. Wind speed shall be maintained within ±10 percent of the test level during a test period.

11.1.2 Zero Mile-Per-Hour Wind Speed

This standard may be used to measure loss rates at a nominal wind speed level of 0 miles per hour by maintaining the wind speed level at less than 0.5 miles per hour. The atmosphere in the wind tunnel and test room shall not be allowed to attain a hydrocarbon concentration greater than 10 percent of the lower explosive limit (LEL).

11.2 DATA TO BE RECORDED

11.2.1 Test Item

A description of the test fitting shall be recorded, including the name of the manufacturer and any model name or number. Dimensions of the test fitting and its position in the wind tunnel shall be recorded on a drawing. The drawing shall also show the orientation of any nonsymmetric features of the test fitting (for example, the pin of a deck support leg). The plumbness of the fitting shall also be recorded in terms of out-of-plumbness expressed in units of inches per foot. Photographs shall also be taken to document the test fitting and its arrangement on the test vessel and fit-up within the wind tunnel.

11.2.2 Instruments

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

11.2.3 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. Each of the following test data shall be recorded during each measurement period.

11.2.3.1 Wind Speed and Time

The wind speed of the air flow in the wind tunnel and the time of the reading shall be observed simultaneously. The wind speed shall be determined by continuous record averaging over a 30-second time period. Readings shall be recorded at intervals of 1 hour or less.

11.2.3.2 Weight, Temperature, and Time

The weight of the test item assembly, the temperature of the air in the wind tunnel, the temperature of the test liquid, the temperature of the air in the test room, the temperature of the scale load cell, and the time of the readings shall be observed simultaneously. The sequence of readings shall be controlled by the data acquisition system, which shall be programmed to first shut off the air blower, then pause for 1 minute to allow air movement to subside in the wind tunnel. It shall then record the data and finally reactivate the blower. Each reading shall be the arithmetic mean of 30 observations made within a period of no more than 5 minutes while the blower is off. Readings shall be recorded at intervals of 1 hour or less.

11.2.3.3 Voltage and Time

The voltage delivered by the power supply to the scale load cells and the time of the readings shall be observed simultaneously. Readings shall be recorded at intervals of 1 hour or less.

11.2.3.4 Atmospheric Pressure and Time

The atmospheric pressure and the time of the readings shall be observed simultaneously. Readings shall be recorded at intervals of 1 hour or less.

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.

11.3 DURATION OF TEST

Fittings that exhibit a high rate of loss experience a correspondingly high rate of evaporation at the surface of the test liquid. The initial loss rate observed for these fittings may be unstable due to the evaporative cooling effect on the temperature of the test liquid at its surface. To test for stable conditions, trial observations shall be made until steady readings are obtained. Observations shall then be recorded for a period of not less than 24 hours after obtaining steady readings. Test fittings that exhibit a low rate of loss may require a longer period to establish their loss rate.

An indication of appropriate test duration may be obtained by performing the uncertainty analysis described in Appendix B while the test is in progress, and observing the change in the calculated uncertainty over time.

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 LOSS RATE

The loss rate (L) shall be obtained from measurements of weight, time, temperature, and atmospheric pressure. Individual readings of the weight of the test assembly are determined as the arithmetic mean of a series of observations (see 11.2.3.2). The standard deviation of each reading shall be calculated.

The loss rate and its variance, along with the uncertainty based on a 95 percent confidence interval, shall be determined from a correlation of the measurements of weight and time to the effect of temperature variation during the test period, as described in Appendix A.

12.3 VAPOR PRESSURE FUNCTION

The vapor pressure function (P^*), as described in the API MPMS, Chapter 19.2, shall be determined from the mean of the measurements of test liquid temperature (T, °F) and the mean of the measurements of atmospheric pressure (P_a) recorded during the test period, using Equations 1, 2, and 3.

$$(T, °\mathrm{R}) = (T, °F) + 459.67 \quad (1)$$

$$P = \exp\left[A_p - \frac{B_p}{(T, °\mathrm{R})}\right] \quad (2)$$

$$P^* = \frac{P/P_a}{(1 + [1 - (P/P_a)]^{0.5})^2} \quad (3)$$

Where:

P = the true vapor pressure of the test liquid.
A_p = 13.824 (dimensionless) for n-hexane.
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 LOSS FACTOR

The loss factor (K_f) for each test shall be calculated from the loss rate (L) and the vapor pressure function (P^*) using Equations 4 and 5.

$$L_f = (L, \mathrm{lb/hr})(24\ \mathrm{hr/day})(365.25\ \mathrm{day/yr}) \quad (4)$$

$$K_f = \left(\frac{L_f}{P^*\ M_v K_c}\right) \quad (5)$$

Where:

L_f = the loss rate extrapolated to an annual basis.
M_v = 86.18 (lb/lb-mole) for n-hexane.
K_c = 1.0 (dimensionless) for n-hexane.

12.5 MULTIPLE TESTS

If multiple tests have been conducted at the same level of wind speed, a loss factor (K_f) shall be calculated for each test. Deck fittings with significant nonsymmetric features that have been tested at multiple orientations for a given level of wind speed shall have a loss factor determined for each orientation.

12.6 UNCERTAINTY ANALYSIS

Determine the uncertainty in the calculated loss factor, K_f, by using the uncertainty analysis procedure described in Appendix B.

12.7 LOSS FACTOR DETERMINATION

A curve shall be fit to a plot of the calculated loss factors (K_f) versus wind speed (V). The curve shall be fit using the procedure described in Appendix C, and shall be of the following form:

$$K_f = K_{fa} + K_{fb}V^m \qquad (6)$$

Where:

K_{fa} = a loss factor constant independent of wind speed.
K_{fb} = a wind-speed-dependent loss factor coefficient.
V = wind speed.
m = a wind-speed-dependent exponent.

13 Report of Test Results

13.1 REPORT

The report of a laboratory test to determine the loss factor of a test fitting of an external floating-roof tank shall include the following:

a. Name and location of the laboratory.
b. Description and drawings of the test apparatus.
c. Name and location of the test fitting manufacturer.
d. Reid vapor pressure of the test liquid, as required in 7.6.2.
e. Description and drawings of the test fitting, 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 calculations, as outlined in Section 12.
i. Results of the uncertainty analysis, as outlined in Appendix B.
j. Results of the loss factor equation determination, as outlined in Appendix C.

13.2 LOSS RATE CURVE

The results of an individual test at a given wind speed and orientation of test fitting shall be recorded on a loss rate curve, showing each reading of weight loss and time. The values shown on the curve shall be the arithmetic mean of the observations as described in 11.2.3.2, after the weight loss values have been corrected for variations in temperature, as required in 12.2. A typical loss rate curve is shown in Figure 4.

An accompanying table shall list the date and time, wind speed, and corrected weight for each reading, as well as the standard deviation of the wind speed and the weight measurements. The temperatures of the test liquid, the air in the wind tunnel, the air in the test room, and the scale load cell shall be shown for each reading. The atmospheric pressure in the test room shall also be listed for each reading.

13.2.1 Coordinates

Loss rate curves shall be drawn with time as the abscissa and weight loss as the ordinate.

13.2.2 Display

The loss rate curve shall show the individual readings and the first order polynomial curve of the correlation equation fit to the data in accordance with Appendix A. The slope of the temperature-corrected loss rate curve shall be expressed as a change in weight over time along with the uncertainty based on a 95 percent confidence interval, in units of pounds per hour. Each loss rate curve shall list the test fitting description, the level of wind speed, the orientation of the fitting (if applicable), and the names of the manufacturer and the laboratory.

13.3 LOSS FACTOR GRAPH

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

13.3.1 Coordinates

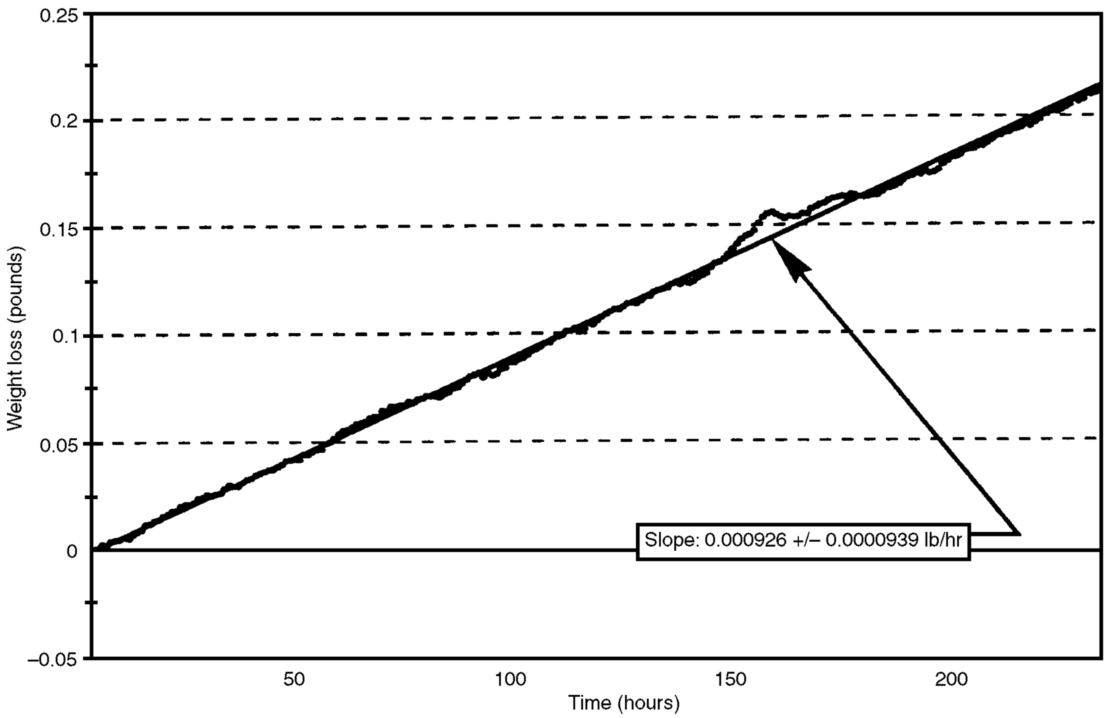
Loss factor graphs shall be drawn with wind speed as the abscissa and loss factor as the ordinate.

13.3.2 Display

The loss factor determined for each test shall be shown as a data point with its 95 percent confidence limits on the loss factor graph. 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 loss factor graph shall list the test fitting description and the names of the manufacturer and the laboratory.

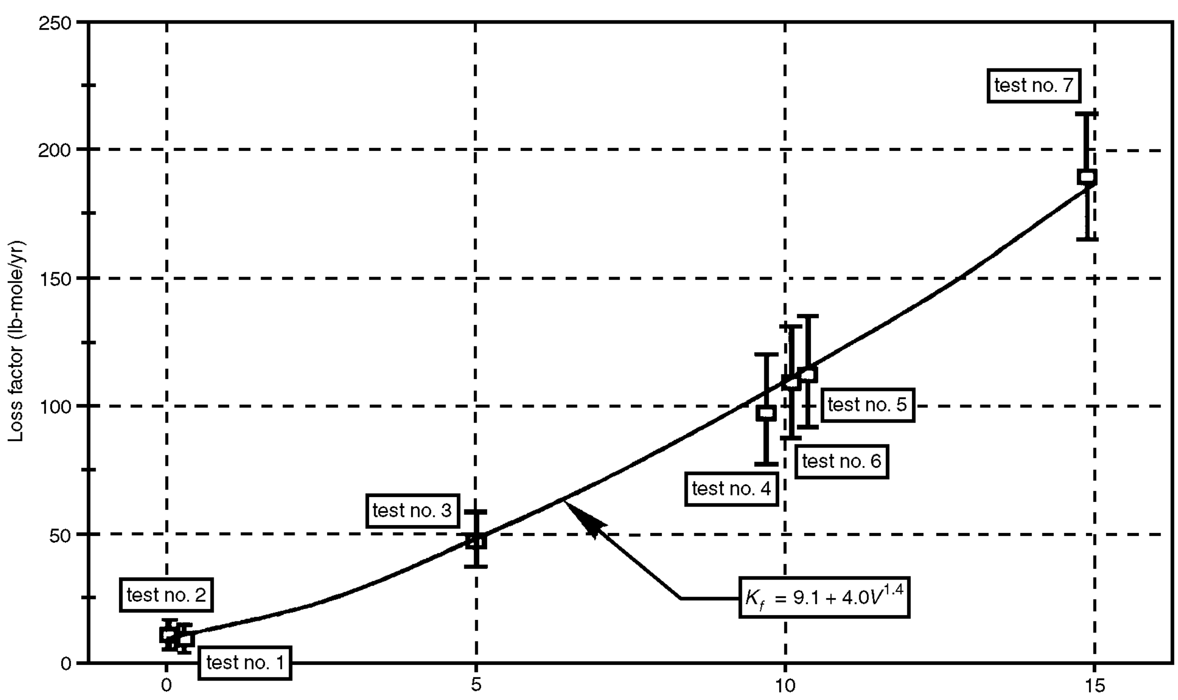
14 Precision and Bias

The uncertainty in a measured evaporative 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 B, which uses the uncertainties in the individual measurements that include the effects of random error (imprecision) and systematic error (bias).



Note: Test fitting description: Gasketed access hatch;
Wind speed: 10 mph;
Manufacturer: Tanks-R-Us;
Laboratory: Tests-R-Us.

Figure 4—Typical Loss Rate Curve



Note: Test fitting description: Gasketed access hatch;
Manufacturer: Tanks-R-Us;
Laboratory: Tests-R-Us.

Figure 5—Typical Loss Factor Graph

APPENDIX A—LOSS RATE DETERMINATION

A.1 General

Appendix A describes a method for determining the loss rate from the test data of a deck-fitting loss factor test. The method includes correcting the test assembly weight readings for variations in the temperature of the scale load cell or data acquisition system.

The temperature of the air in the test room is to be maintained within ±5°F of a selected temperature, as listed in 7.2. Variations in temperature of the test room can cause variations in the temperature of the scale load cell and of the data acquisition system, when the data acquisition system is also in the test room. Although the test room temperature variations may be small, they can cause variations in the weight readings, especially for test fittings that have low evaporative loss rates.

The method of weight loss temperature correction described in this Appendix A is written primarily around correcting the weight loss readings for variations in scale load cell temperature. These same methods can also be applied to correct the weight loss readings for variations in the data acquisition system temperature or test liquid temperature, if necessary.

A.2 Nomenclature

The nomenclature used in Appendix A is listed in Table A-1.

Table A-1—Nomenclature for Appendix A

Symbol	Description	Units
a	Coefficient in the weight loss correlation	lb
b	Coefficient in the weight loss correlation	lb/hr
c	Coefficient in the weight loss correlation	lb/hr^2
d	Coefficient in the weight loss correlation	lb/°F
n	Number of weight loss measurements in a test	dimensionless
SSE	Sum of squares due to error, (defined by Equation A.7)	lb
t	Time	hr
t_{mi}	Time of data point i, (i = 1,2,...,n)	hr
T	Scale load cell temperature	°F
T_a	Average scale load cell temperature during a test	°F
T_{mi}	Measured scale load cell temperature during a test at time t_{mi}, (i = 1,2,...,n)	°F
W	Weight loss of the test fitting	lb
W_{ai}	Correlated weight loss at time t_{mi}, (i = 1,2,...,n)	lb
W_{ci}	Corrected weight loss at time t_{mi}, (i = 1,2,...,n)	lb
W_i	Calculated weight loss at time t_{mi}, (i = 1,2,...,n)	lb
W_{mi}	Measured weight loss at time t_{mi}, (i = 1,2,...,n)	lb

Note: See Section 3 for definitions of units abbreviations.

A.3 Weight Loss Temperature Correction

Dead-weight tests performed on scales have shown that the weight indication has a linear response to the load cell temperature as this temperature is varied around an average value. Based on these observations, the measured weight loss readings, W_{mi}, may be corrected to the average scale load cell temperature, T_a, using Equation A-1.

$$W_{ci} = W_{mi} - d(T_{mi} - T_a) \qquad \text{(A-1)}$$

Where:

$$T_a = \frac{1}{n}\sum_{i=1}^{n}(T_{mi}) \qquad \text{(A-2)}$$

The temperature correction coefficient, d, in Equation A-1 may be determined from a dead-weight test on the scale during which the scale load cell temperature is varied.

A.4 Weight Loss Correlation

The temperature-corrected weight loss versus time test data for evaporative loss rate tests on deck fittings that have a large loss rate may be correlated with the second order polynomial of Equation A-3.

$$W = a + bt + ct^2 \qquad \text{(A-3)}$$

The weight loss versus time test data from deck fittings with a large loss rate (for example, slotted guidepole fittings) typically have a decreasing loss rate with time as the test liquid evaporates and the level of the test liquid decreases with time. In these cases, only the initial loss rate indicated by the coefficient b in Equation A-3 is representative of the test fitting loss rate for use in determining the deck-fitting loss factor.

The temperature-corrected weight loss versus time test data for evaporative loss rate tests on deck fittings that have a low loss rate may be correlated with the first order polynomial of Equation A-4.

$$W = a + bt \qquad \text{(A-4)}$$

In these cases, the coefficient b in Equation A-4 is the test-fitting loss rate that is to be used in determining the deck-fitting loss factor.

A.5 Alternate Method of Weight Loss Temperature Correction

An alternate method of determining the temperature correction coefficient, d, is from a regression of the evaporative loss factor test data. In this case, the coefficients a, b, and c in Equation A-3 are determined at the same time as the temperature correction coefficient d using the regression method described below.

One should consider the data set for a particular test which consists of paired values of the variables W_{mi}, T_{mi}, and t_{mi} for $i = 1,2,...,n$, where the subscript m designates a measured value. One should determine the values of the coefficients a, b, c, and d so that Equation A-5 best fits the entire set of test data for a particular test.

$$W = a + bt + ct^2 + d(T - T_a) \quad \text{(A-5)}$$

For a specific time, t_{mi}, the measured weight loss is W_{mi}, and the measured scale temperature is T_{mi}. Equation A-6 would predict a weight loss of W_i.

$$W_i = a + bt_{mi} + ct_{mi}^2 + d\ (T_{mi} - T_a) \quad \text{(A-6)}$$

where the average scale load cell temperature, T_a, is determined from Equation A-2.

The difference between the measured weight loss, W_{mi}, and the predicted loss, W_i, from Equation A-6 is due to the inability of the weight loss correlation to exactly predict the measured weight loss. The sum of squares due to error, SSE, is defined by Equation A-7.

$$SSE = \sum_{i=1}^{n} (W_i - W_{mi})^2 \quad \text{(A-7)}$$

To determine the best values for the coefficients a, b, c and d, the following four conditions are imposed:

$$\frac{\partial\ \text{SSE}}{\partial a} = 0 \quad \text{(A-8)}$$

$$\frac{\partial\ \text{SSE}}{\partial b} = 0 \quad \text{(A-9)}$$

$$\frac{\partial\ \text{SSE}}{\partial c} = 0 \quad \text{(A-10)}$$

$$\frac{\partial\ \text{SSE}}{\partial d} = 0 \quad \text{(A-11)}$$

Substituting Equation A-5 into Equations A-8, A-9, A-10 and A-11, and using Equation A-6, the above four conditions generate four linear algebraic equations with four unknowns, a, b, c and d. These four simultaneous linear algebraic equations can then be solved to yield four expressions for determining the coefficients a, b, c, and d.

A.6 Weight Loss Plots

For each evaporative loss factor test, it is useful to prepare plots of weight loss versus time.

A.6.1 MEASURED AND CALCULATED WEIGHT LOSS PLOTS

Figure A-1 is an example plot of measured weight loss, W_{mi}, and calculated weight loss, W_i, versus time. The plot of measured weight loss, W_{mi}, displays the recorded data of actual weight loss, W_{mi}, measurements. The plot of calculated weight loss, W_i, displays the first or second order weight loss correlation, Equation A-6, at the actual measured scale temperature, T_{mi}.

$$W_i = a + bt_{mi} + ct_{mi}{}^2 + d\ (T_{mi} - T_a) \quad \text{(A-6)}$$

By comparing the plot of measured weight loss, W_{mi}, with the plot of calculated weight loss, W_i, one can visually see how well the weight loss correlation, Equation A-6, fits the measured test data.

A.6.2 CORRECTED AND CORRELATED WEIGHT LOSS PLOTS

Figure A-2 is an example plot of temperature-corrected weight loss, W_{ci}, and correlated weight loss, W_{ai}, versus time. The plot of temperature-corrected weight loss, W_{ci}, displays the measured weight loss after it has been corrected to the average scale load cell temperature, T_a, using Equation A-1.

$$W_{ci} = W_{mi} - d(T_{mi} - T_a) \quad \text{(A-1)}$$

The plot of correlated weight loss, W_{ai}, displays the first order weight loss correlation at the average scale temperature, T_a, using Equation A-12.

$$W_{ai} = bt_{mi} \quad \text{(A-12)}$$

By comparing the plot of temperature-corrected weight loss, W_{ci}, with the plot of correlated weight loss, W_{ai}, one can visualize how well the weight loss correlation, Equation A-12, fits the temperature-corrected weight loss test data.

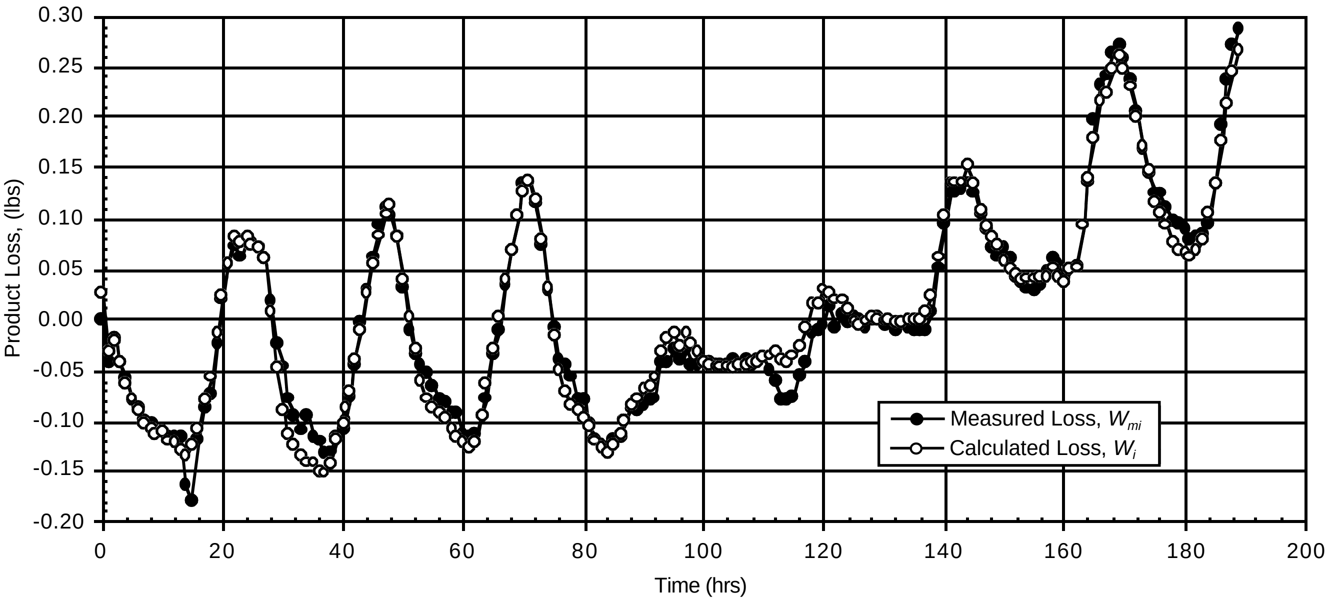


Figure A-1—Measured and Calculated Weight Loss Versus Time

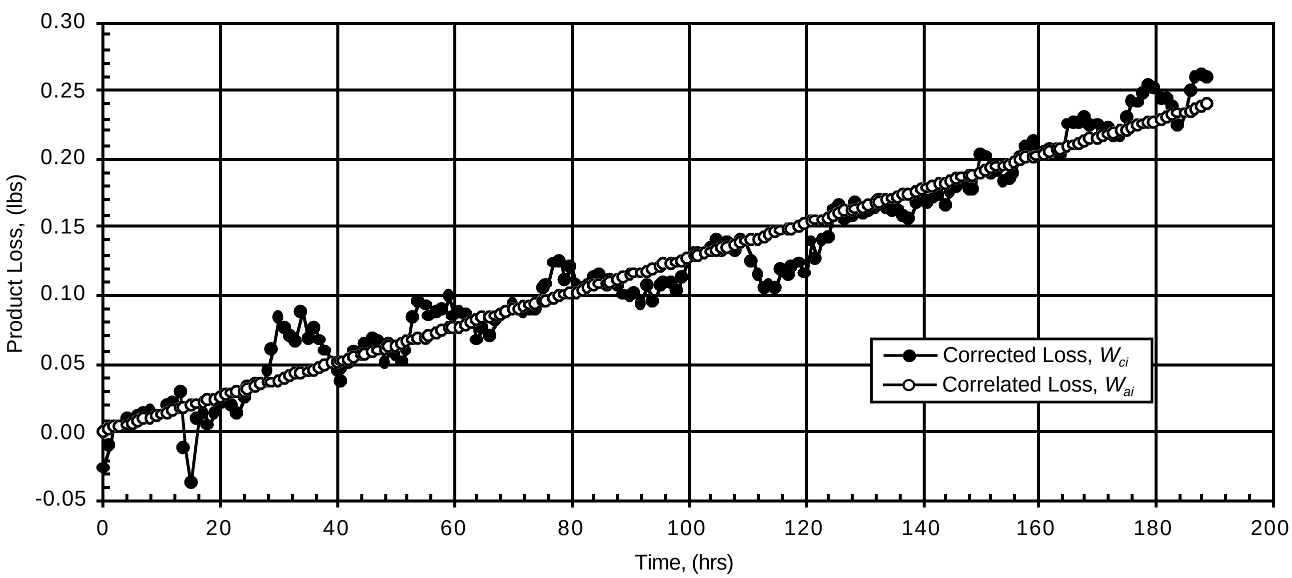


Figure A-2—Corrected and Correlated Weight Loss Versus Time

APPENDIX B—UNCERTAINTY ANALYSIS

B.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 B describes a calculation method that shall be used to determine the uncertainty in the deck-fitting loss factor, K_f, that results from the effects of the individual measurement uncertainties. The results of these calculations shall be included in the report of test results.

B.2 Definitions

The following definitions are used in Appendix B:

X = measured quantity.
U_x = absolute uncertainty in X.
E_x = per unit uncertainty in X.

From these definitions it follows that:

$$E_x = U_x/X \tag{B-1}$$

The per unit uncertainty, E_x, used in this standard shall be based on a 95 percent confidence interval, 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 B-2.

$$X \pm U_x \tag{B-2}$$

B.3 Nomenclature

The nomenclature used in Appendix B consists of the nomenclature previously listed in 3.3, as well as that listed in Table B-1.

Table B-1—Nomenclature for Appendix B

Symbol	Description	Units
F	Defined by Equation B-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_f}	Deck-fitting loss factor	dimensionless
E_L	Deck-fitting loss rate	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_f}	Deck-fitting loss factor	lb–mole/yr
U_L	Deck-fitting loss rate	lb/hr
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

Note: See Section 3 for definitions of abbreviations.

B.4 Uncertainty Formulas

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

B.4.1 UNCERTAINTY IN THE VAPOR PRESSURE

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

$$E_P = [A_p^2 E_{A_p}^2 + (B_p/T)^2 (E_{B_p}^2 + E_T^2)]^{0.5} \tag{B-3}$$

The per unit uncertainties of the constants in the vapor pressure equation, 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 D 323. The 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, 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 test liquid temperature recorded during the 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.

B.4.2 UNCERTAINTY IN THE VAPOR PRESSURE FUNCTION

In determining the per unit uncertainty of the vapor pressure function, 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 B-4.

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

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

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

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 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 B-6.

$$E_{P*} = FE_{R_p} \quad \text{(B-6)}$$

Where:

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

B.4.3 UNCERTAINTY IN THE DECK-FITTING LOSS FACTOR

The per unit uncertainty in the deck-fitting loss factor, E_{K_f}, may be calculated from Equation B-8.

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

The per unit uncertainty in the deck-fitting loss rate shall include any known bias errors in the calibration of the weight measurement instrumentation, as well as random errors resulting from variations in the temperature-corrected weight readings that affect the weight loss versus time slope determination described in Appendix A.

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.

B.5 Example Uncertainty Analysis

This section presents an example uncertainty analysis for a deck fitting loss factor test. Table B-2 summarizes the results of the uncertainty analysis.

B.5.1 UNCERTAINTY IN THE VAPOR PRESSURE

Calculate P:

A_p = 13.824 (dimensionless) (from the test data)

B_p = 6,907.2°R (from the test data)

T = 543.19°R (from the test data)

From Equation 2 (see 12.3):

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

$= \exp [(13.824) - (6,907.2/543.19)]$

= 3.0283 psia

Calculate E_P:

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

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

E_T = 5.5229 x 10^{-3} (from the test data)

From Equation B-3:

$$E_P = [A_p{}^2 E_{A_p}{}^2 + (B_p/T)^2(E_{B_p}{}^2 + E_T{}^2)]^{0.5}$$

$$= [(13.824)^2(1.0000 \times 10^{-3})^2 + (6,907.2/543.19)^2((1.0000 \times 10^{-3})^2 + (5.5229 \times 10^{-3})^2)]^{0.5}$$

$$= 7.2698 \times 10^{-2}$$

Calculate U_P:

$U_P = E_P P$

= (7.2698 x 10^{-2})(3.0283)

= 0.22015 psia

Table B-2—Summary of Example Uncertainty Analysis Results

Description	Symbol	Units	Value
Given test data:			
Wind speed	V	mi/hr	11.900
	U_v	mi/hr	0.50000
	E_v	dimensionless	0.042017
Deck-fitting loss rate	L	lb/hr	0.065520
	U_L	lb/hr	3.2760×10^{-3}
	E_L	dimensionless	5.0000×10^{-2}
Stock liquid temperature	T	°F	83.520
	T	°R	543.19
	U_T	°R	3.0000
	E_T	dimensionless	5.5229×10^{-3}
Vapor pressure constant	A_p	dimensionless	13.824
	U_{A_p}	dimensionless	1.3824×10^{-2}
	E_{A_p}	dimensionless	1.0000×10^{-3}
Vapor pressure constant	B_p	°R	6907.2
	U_{B_p}	°R	6.9072
	E_{B_p}	dimensionless	1.0000×10^{-3}
Atmospheric pressure	P_a	psia	14.696
	U_{P_a}	psia	0.44088
	E_{P_a}	dimensionless	3.0000×10^{-2}
Vapor molecular weight	M_v	lb/lb–mole	86.177
	U_{M_v}	lb/lb–mole	8.6177×10^{-2}
	E_{M_v}	dimensionless	1.0000×10^{-3}
Product factor	K_c	dimensionless	1.0000
	U_{K_c}	dimensionless	0.0
	E_{K_c}	dimensionless	0.0
Calculated test results:			
Vapor pressure	P	psia	3.0283
	U_P	psia	0.22015
	E_P	dimensionless	7.2698×10^{-2}
Ratio of vapor pressure to atmospheric pressure	R_p	dimensionless	0.20606
	U_{R_p}	dimensionless	1.6206×10^{-2}
	E_{R_p}	dimensionless	7.8645×10^{-2}
Vapor pressure function	$P*$	dimensionless	0.057624
	U_{P*}	dimensionless	5.0861×10^{-3}
	E_{P*}	dimensionless	8.8263×10^{-2}
Deck-fitting loss factor	K_f	lb–mole/yr	115.66
	U_{K_f}	lb–mole/yr	11.733
	E_{K_f}	dimensionless	0.10145

Note: See 3.2 for definition of abbreviations.

B.5.2 UNCERTAINTY IN THE RATIO OF VAPOR PRESSURE TO ATMOSPHERIC PRESSURE

Calculate R_p:

$$P = 3.0283 \text{ psia (from B.5.1)}$$
$$P_a = 14.696 \text{ psia (from the test data)}$$

From Equation B-4:

$$R_p = P/P_a = (3.0283)/(14.696) = 0.20606$$

Calculate E_{R_p}:

$$E_P = 7.2698 \times 10^{-2} \text{ (from B.5.1)}$$
$$E_{P_a} = 3.0000 \times 10^{-2} \text{ (from the test data)}$$

From Equation B-5:

$$E_{R_p} = [E_P^2 + E_{P_a}^2]^{0.5} = [(7.2698 \times 10^{-2})^2 + (3.0000 \times 10^{-2})^2]^{0.5} = 7.8645 \times 10^{-2}$$

Calculate U_{R_p}:

$$U_{R_p} = E_{R_p} R_p = (7.8645 \times 10^{-2})(0.20606) = 1.6206 \times 10^{-2}$$

B.5.3 UNCERTAINTY IN THE VAPOR PRESSURE FUNCTION

Calculate P^*:

$$R_p = 0.20606 \text{ (from B.5.2)}$$

From Equation 3:

$$P^* = R_p/[1 + (1 - R_p)^{0.5}]^2 = (0.20606)/[1 + (1 - 0.20606)^{0.5}]^2 = 0.057624$$

Calculate E_{P*}:

$$E_{R_p} = 7.8645 \times 10^{-2} \text{ (from B.5.2)}$$

From Equation B-7:

$$F = \left[\frac{1 + (1 - R_p)^{0.5}}{1 + (1 - R_p)^{0.5} - R_p}\right] = \left[\frac{1 + (1 - 0.20606)^{0.5}}{1 + (1 - 0.20606)^{0.5} - 0.20606}\right] = 1.1223$$

From Equation B-6:

$$E_{P*} = F E_{R_p} = (1.1223)(7.8645 \times 10^{-2}) = 8.8263 \times 10^{-2}$$

Calculate U_{P*}:

$$U_{P*} = E_{P*} P^* = (8.8263 \times 10^{-2})(0.057623) = 5.0861 \times 10^{-3}$$

B.5.4 UNCERTAINTY IN THE DECK-FITTING LOSS FACTOR

Calculate K_f:

$$L = 0.065520 \text{ lb/hr (from the test data)}$$
$$P^* = 0.057624 \text{ (from B.5.3)}$$
$$M_v = 86.177 \text{ lb/lb-mole (from the test data)}$$
$$K_c = 1.0000 \text{ (from the test data)}$$

From Equations 4 and 5 (see 12.4):

$$K_f = [(24)(365.25)L]/(P^* M_v K_c) = [(24)(365.25)(0.065520)]/[(0.057624)(86.177)(1.0000)] = 115.66 \text{ lb-mole/yr}$$

Calculate E_{K_f}:

$$E_L = 5.0000 \times 10^{-2} \text{ (from the test data)}$$
$$E_{P*} = 8.8263 \times 10^{-2} \text{ (from B.5.3)}$$
$$E_{M_v} = 1.0000 \times 10^{-3} \text{ (from the test data)}$$
$$E_{K_c} = 0 \text{ (from the test data)}$$

From Equation B-8:

$$E_{K_f} = [E_L^2 + E_{P*}^2 + E_{M_v}^2 + E_{K_c}^2]^{0.5} = [(5.0000 \times 10^{-2})^2 + (8.8263 \times 10^{-2})^2 + (1.0000 \times 10^{-3})^2 + (0)^2]^{0.5} = 0.10145$$

Calculate U_{K_f}:

$$U_{K_f} = E_{K_f} K_f = (0.10145)(115.66) = 11.733 \text{ lb-mole/yr}$$

Summary:

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

$$K_f = 115.66 \pm 11.73 \text{ lb-mole/yr}$$

at a wind speed of:

$$V = 11.90 \pm 0.50 \text{ mi/hr.}$$

APPENDIX C—DETERMINATION OF LOSS FACTOR EQUATION

C.1 General

This appendix provides the method for determining the loss factor equation from the test data for a particular deck fitting. The loss factor equation is determined by fitting a curve to the plot of the loss factors (K_f) calculated for each test versus wind speed (V). The test data are weighted, for orientation-dependent deck fittings, so as to give equal weight to each orientation at a given level of wind speed.

Appendix C 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 previously listed in 3.3, as well as that listed in Table C-1.

Table C-1—Nomenclature for Appendix C

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

C.3 Loss Factor Equation

The loss factor equation is determined from the loss factors (K_f) 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.

$$K_f = K_{fa} + K_{fb}V^m \qquad \text{(C-1)}$$

The curve of Equation C-1 shall be fit to the data by using a standard least squares regression routine 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_{fa} from each side of Equation C-1:

$$K_f - K_{fa} = K_{fb}V^m \qquad \text{(C-2)}$$

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

$$\log(K_f - K_{fa}) = \log(K_{fb}V^m) \qquad \text{(C-3)}$$

which may also be expressed as:

$$\log(K_f - K_{fa}) = \log(K_{fb}) + m\ \log(V) \qquad \text{(C-4)}$$

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

$$\log(E_{net}) = \log(K_{fb}) + m\ \log(V) \qquad \text{(C-5)}$$

Where:

$$E_{net} = K_f - K_{fa} \qquad \text{(C-6)}$$

The coefficient K_{fa} is determined as the loss factor (K_f) calculated from one or more 0-mile-per-hour tests. The 0-mile-per-hour test may be conducted in accordance with 11.1.2, or may be conducted in accordance with the API MPMS, Chapter 19.3, Part E. If more than one test is conducted at the 0-mile-per-hour wind speed level, the mean of the loss factors from each 0-mile-per-hour test shall be calculated to determine K_{fa}.

A net emission level (E_{net}) is determined for each test conducted at a non-zero wind speed by subtracting the 0-mile-per-hour loss factor (K_{fa}) from the loss factor (K_f) that was calculated at each of the non-zero wind speeds.

If multiple tests have been conducted at the same level of wind speed and orientation of the deck fitting, for orientation-dependent deck fittings, the database shall be adjusted in order to achieve equal weighting of each orientation. Equal weighting shall be achieved by generating the same number of data points at each deck-fitting orientation for a given level of wind speed. This shall be accomplished by repeating the data for those orientation cases which did not have multiple tests until an equal number of data points are available for each case. If, for example, a deck fitting that is orientation-dependent had two tests at a 0-degree orientation, one test at 45 degrees, and one test at 90 degrees, then the loss factors calculated at 45 degrees and 90 degrees shall each be used twice in the database. Using the data twice at these two orientations and using each of the two loss factors calculated at the 0-degree orientation once results in two data points for each orientation at that wind speed level.

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 m and $\log(K_{fb})$. The coefficient K_{fb} is then determined from Equation C-7.

$$K_{fb} = 10^{(\log(K_{fb}))} \qquad \text{(C-7)}$$

The values of K_{fa}, K_{fb}, and m determined by this procedure are the constants in the loss factor equation for the tested deck fitting.

C.4 Example Determination of Loss Factor Equation

This section presents an example determination of a deck-fitting loss factor equation. Table C-2 lists the loss factors (K_f) calculated for each of the tests that are assumed to have been conducted in the example, Table C-3 summarizes the data-

Table C-2—Example Loss Factors

Test No.	Nominal Wind Speed Level (mph)	Wind Speed (V) (mph)	Orientation	Loss Factor (K_f) (lb-mole/yr)
1	0	0.421	0	21.5
2	0	0.350	0	26.9
3	5	4.91	0	193.7
4	5	5.03	0	183.6
5	5	5.12	45	81.43
6	5	4.96	45	73.17
7	5	5.10	90	79.83
8	10	9.36	0	687.2
9	10	10.2	0	646.8
10	10	10.1	45	143.9
11	10	9.95	90	458.1
12	10	10.1	90	199.1
13	15	14.2	0	1473.0
14	15	14.1	45	217.1
15	15	14.6	90	671.7

base for the least squares regression, and Table C-4 summarizes the results of the loss factor equation determination.

The coefficient, K_{fa}, is determined as the arithmetic mean of all loss factors at the 0-mile-per-hour wind speed level. The 0-mile-per-hour wind speed level includes all tests at wind speeds below 0.5 mile per hour (see 11.1.2), and is not orientation-dependent. The coefficient, K_{fa}, is therefore the average of the loss factors from Tests 1 and 2, as shown in Equation C-8.

$$K_{fa} = (21.5 + 26.9)/2 \qquad \text{(C-8)}$$

$$K_{fa} = 24.2 \text{ lb-mole/yr}$$

The number of data points at each non-zero level of wind speed shall be weighted equally for each orientation. In that certain orientations at 5 and 10 miles per hour have 2 data points, the orientations having only one data point must be used twice. The database is then compiled by determining the net emission level, E_{net}, for each data point, as well as the log of the wind speed (V) and the log of the net emission level (E_{net}). These steps are summarized in Table C-3.

The data in Table C-3 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 m and $\log(K_{fb})$ generated by the least squares regression are as follows:

$$m = 1.84$$

$$\log(K_{fb}) = 0.608$$

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

$$K_{fb} = 4.05 \text{ lb-mole/(mph)}^m\text{yr}$$

The values for the loss factor equation constants K_{fa}, K_{fb}, and m determined by this procedure are listed in Table C-4.

Table C-3—Example Loss Factor Equation Database

Test No.	Nominal Wind Speed Level (mph)	Orientation	Wind Speed (V) (mph)	Log (V)	Loss Factor (K_f) (lb-mole/yr)	Loss Factor (K_{fa}) (lb-mole/yr)	E_{net}	Log (E_{net})
3	5	0	4.91	0.691	193.7	24.2	169.5	2.229
4	5	0	5.03	0.702	183.6	24.2	159.4	2.202
5	5	45	5.12	0.709	81.43	24.2	57.23	1.758
6	5	45	4.96	0.695	73.17	24.2	48.97	1.690
7	5	90	5.10	0.708	79.83	24.2	55.63	1.745
7	5	90	5.10	0.708	79.83	24.2	55.63	1.745
8	10	0	9.36	0.971	687.2	24.2	663.0	2.822
9	10	0	10.2	1.009	646.8	24.2	622.6	2.794
10	10	45	10.1	1.004	143.9	24.2	119.7	2.078
10	10	45	10.1	1.004	143.9	24.2	119.7	2.078
11	10	90	9.95	0.998	458.1	24.2	433.9	2.637
12	10	90	10.1	1.004	199.1	24.2	174.9	2.243
13	15	0	14.2	1.152	1473.0	24.2	1449.0	3.161
14	15	45	14.1	1.149	217.1	24.2	192.9	2.285
15	15	90	14.6	1.164	671.7	24.2	647.5	2.811

Table C-4—Example Loss Factor Equation Constants

Coefficient (K_{fa}) (lb-mole/yr)	Coefficient (K_{fb}) (lb-mole/(mph)^{m}yr)	Exponent (m) (dimensionless)
24	4.1	1.8

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

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 dimensionless coefficients P^* and K_c times a loss factor, K_f, as described in 3.2. The loss factor K_f, while not a loss rate, is also expressed as lb-mole/yr. The equivalent SI unit for the loss rate and the loss factor is the kilogram-mole per year, designated *kmol/yr*. As with inch pound units, the loss factor in kmol/yr must be multiplied by the dimensionless coefficients P^* and K_c to obtain a loss rate in kmol/yr.

APPENDIX E—BIBLIOGRAPHY

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

API

Manual of Petroleum Measurement Standards

Chapter 19.1, "Evaporative Loss from Fixed-Roof Tanks"

Std 653 *Tank Inspection Repair, Alteration, and Reconstruction*

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E 456-92 *Terminology Relating to Quality and Statistics*.

E 1187-90 *Terminology Relating to Laboratory Accreditation*

E 1267-88 *Guide for ASTM Standard Specification Quality Statements*

E 1488-92 *Guide for Statistical Procedures to Use in Developing and Applying ASTM Test Methods*

[2]American Society for Testing and Materials, 100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428.

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