Manual of Petroleum Measurement Standards Chapter 4—Proving Systems

Section 7—Field Standard Test Measures

THIRD EDITION, APRIL 2009

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Measurement Coordination Department

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Foreword

This edition of this standard consolidates the latest changes and improved technology in field standard test measures since it was first published in October 1988. Units of measurement in this standard are U.S. customary (USC) units and metric (SI) units consistent with North American industry practices.

This standard has been developed through the cooperative efforts of many individuals from industry under the sponsorship of the American Petroleum Institute (API) and with the assistance of the National Institute of Standards and Technology (NIST).

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Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, D.C. 20005, standards@api.org.

Contents

Introduction

The primary purpose of a field standard test measure is to provide a standardized volume, used for the calibration of displacement and tank provers, when calibrated by the waterdraw method. A field standard test measure is a vessel fabricated to meet specific design criteria and calibrated by a National Metrology Institute (NMI). The NMI of the United States is the National Institute of Standards and Technology (NIST). Throughout this document, issues of traceability are addressed by reference to NIST. All field standard test measures used for prover calibrations in the United States shall have a current “Report of Calibration,” issued by NIST.

In countries other than the United States, other NMIs may be used. On some occasions, the same test measure may be calibrated by two or more different NMIs for use in different countries, e.g. NIST and the Canadian Standards Agency (CSA) may both calibrate the same test measure. Calibrations by different NMIs may result in different volumes. Typically, this is due to different reference conditions, procedures, methods (gravimetric vs volumetric), calibration fluids and drain times.

Chapter 4—Proving Systems
Section 7—Field Standard Test Measures

1 Scope

This standard details the essential elements of field standard test measures by providing descriptions, construction requirements, as well as inspection, handling, and calibration methods. Bottom-neck scale test measures and prover tanks are not addressed in this document. The scope of this standard is limited to the certification of "delivered volumes" of test measures.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies.

API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 1, *Vocabulary*

API *MPMS* Chapter 4.2, *Displacement Provers*

API *MPMS* Chapter 4.4, *Tank Provers*

API *MPMS* Chapter 4.8, *Operation of Proving Systems*

API *MPMS* Chapter 4.9, *Methods of Calibration for Displacement and Volumetric Tank Provers*

API *MPMS* Chapter 7, *Temperature Determination*

API *MPMS* Chapter 11, (all sections) *Physical Properties Data*

API *MPMS* Chapter 12, (all sections) *Calculation of Petroleum Quantities*

API *MPMS* Chapter 13, (all sections) *Statistical Aspects of Measuring and Sampling*

NIST Calibration Services for Liquid Volume [1], *Quality System Manual QM-IV-8361 for the Liquid Volume Calibration Services*

NIST Handbook 105-3, *Specifications and Tolerances for Reference Standards and Field Standard Weights and Measures, Part 3: Specifications and Tolerances for Graduated Neck Type Volumetric Field Standards*

NIST Special Publication 250-72, *NIST Calibration Services for Liquid Volume*

NIST Technical Note 1297 (1994), *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*

NOTE All references in this standard are to the most current NIST documents. More current revisions of these documents may replace those listed above. Refer to the NIST web address: www.nist.gov/fluid_flow or http://ts.nist.gov/weightsandmeasures/pubs.cfm for the most current documents.

3 Terms and Definitions

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

3.1
borosilicate glass
A glass with a low coefficient of thermal expansion.

1 National Institute of Standards and Technology, 100 Bureau Drive, Stop 3460, Gaithersburg, Maryland 20899, www.nist.gov.

3.2
calibrated volume
Also defined as the field standard test measure base volume (BMV); the delivered volume of a field standard test measure, at its reference temperature, between its defined “full and empty” levels.

3.3
calibration
A set of operations which establish, under specified conditions, the relationship between the values indicated by a measuring device and the corresponding known values indicated when using a suitable measuring standard.

3.4
cessation of main flow
During the draining of a field standard test measure, the moment when the full discharging water stream “breaks” and becomes a small trickle.

3.5
clingage
The film of liquid that adheres to the inside surface of a field standard test measure after it has been drained and is considered empty.

3.6
contained volume
The volume of liquid (at the reference temperature) held by field test measure filled to the zero reference mark. It is larger than the delivered volume due to clingage of liquid to the inside walls of the test measure. It is also the volume of liquid necessary to fill a clean, dry, empty, test measure to the zero reference mark on the neck scale. “Contained volume” was previously described as “to contain.” The contained volume *is not used* in the calibration of provers.

3.7
delivered volume
The volume of liquid (at the reference temperature) that exits a test measure when it is emptied from its full condition and drained in accordance with the prescribed draining time. In previous standards and certifications’ “delivered volume” was described as “to deliver.” The delivered volume is the only volume used in the calibration of provers.

3.8
field standard test measure
A volumetric, non-pressurized, cylindrical, metal container, with a cylindrical neck containing a gauge glass and scale. Designed to stringent specifications, it “contains” or “delivers” an exact volume between a fixed bottom or a bottom shut-off valve and an upper-neck scale reading.

3.9
high-resolution type
A field standard test measure designed with a smaller-diameter neck, which is used to achieve greater neck volume resolution. This type of test measure is also called “high-sensitivity” or “high-accuracy.”

3.10
reference temperature
The temperature at which the test measure is intended to “contain volume” or to “deliver volume” at its nominal capacity.

3.11
slicker-plate test measure
A vessel similar to a field standard test measure, except it has no sight glass and neck scale. It is filled so that the liquid just extends above the top of the neck, due to surface tension, where the excess is sheared off by sliding a transparent plate across the top of the neck. Slicker-plate test measures are *not used* in the calibration of provers.

4 Equipment

4.1 General

Design specifications for test measures shall be in accordance with this standard and the latest edition of NIST Handbook 105-3.

4.2 Materials and Fabrication

A vessel used as a field standard test measure shall be constructed of corrosion-resistant stainless steel. All parts of the main body of the test measure shall be made of the same material. All interior seams shall be filled and ground smooth enough to prevent any entrapment of air, liquid, or foreign material.

Fabrication shall ensure that no pockets, dents, or crevices are present that may entrap air or liquid or impair the proper filling or draining of the standard. Any horizontal cross-section shall be circular, and the shape of the vessel shall permit complete emptying and draining. Dimensional requirements for USC units and SI units are shown in Table 1a and Table 1b of NIST Handbook 105-3. See Figure 1 and Figure 2 for typical test measures used for prover calibrations.

Where appropriate, reinforcing bands shall be used to prevent distortion of the measure or field standard when it is full of liquid. The opening at the top of the neck shall be structurally durable because of the thickness of the metal, or it shall be reinforced. The bottom of the field standard test measure shall be designed to prevent distortion when it is filled with liquid and prevent damage during use.

A field standard test measure in use shall be leveled and stand solidly on a surface with its vertical axis normal to that surface.

4.3 Gauge Glass

A field standard test measure shall be equipped with a gauge glass mounted on the side of the neck (see Figure 3). This gauge glass shall be made of borosilicate type glass or equivalent, and shall be free from any irregularities or defects that will distort the appearance of the liquid surface. Any gauge glass made of a substitute material shall be impervious to petroleum products.

The gauge glass shall be installed to facilitate cleaning and removal. Replacement glass shall conform to the original size and bore specified by the manufacturer. The bottom mounting of the gauge glass shall be made leak-proof, without the use of cement, by using compressible gaskets or O-rings. Removal and replacement of the glass shall be accomplished without difficulty and without affecting the calibration of the measure.

4.4 Drain Lines and Outlet Valves

If a drain line extends from the bottom center of a field standard test measure, the downward slope of the line shall provide complete and proper drainage. This drain line shall be sized to provide the maximum drainage rate possible consistent with a smooth and controlled drainage, while emptying the test measure with the drain valve fully open and adhering to the prescribed draining time. Test measure drain valves shall be sealed to indicate whether the valve has been changed, modified, replaced, or repaired in any way that affects the integrity of the volume determined at the last calibration. Many test measures have drain valves that are simply screwed into the drain line. The volume is altered if this valve is turned to a different number of threads, either more or less. The importance of this valve to the calibrated volume cannot be overemphasized and properly sealing drain valves should be an absolute priority for volumetric test measures. A metal-to-metal flange arrangement between the drain line and the drain valve is the preferred method of drain valve connection.

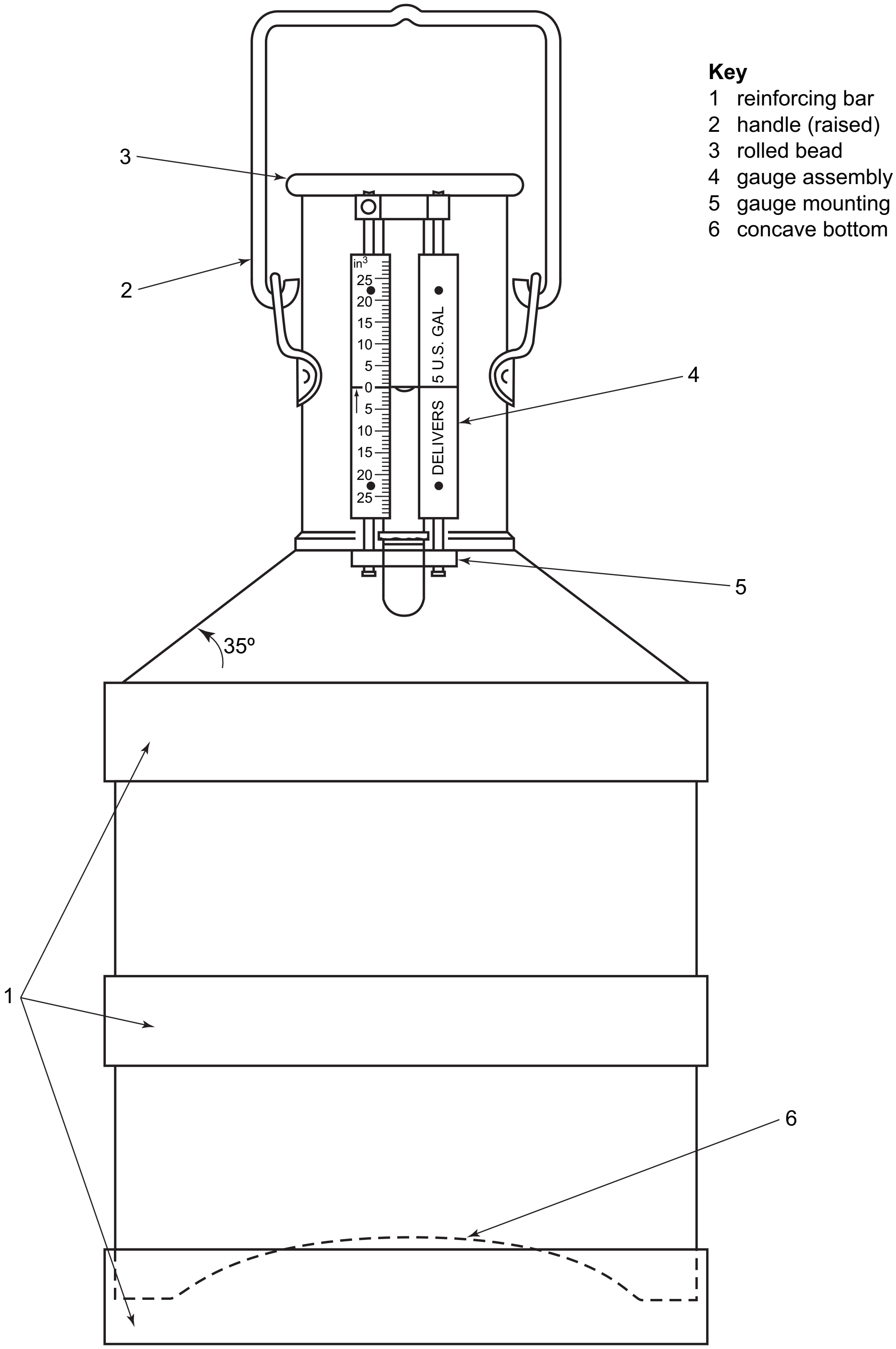
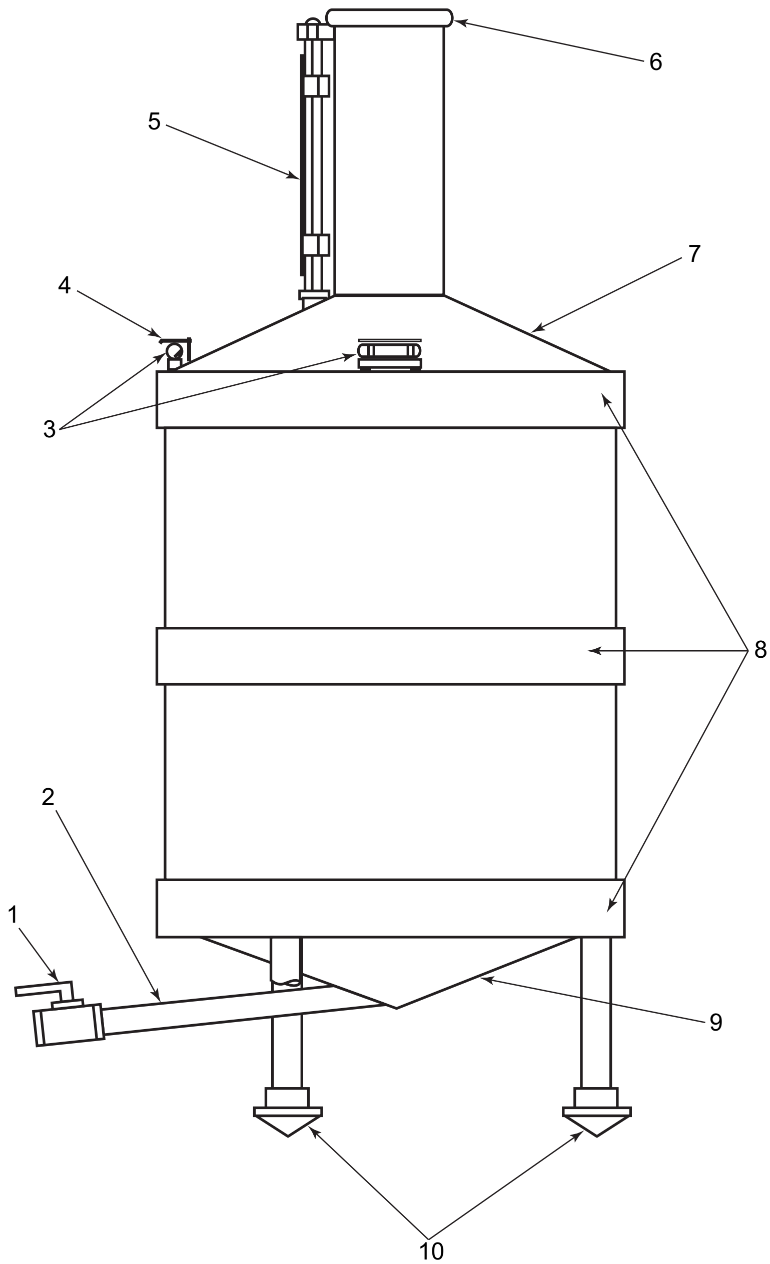


Figure 1—Field Standard Test Measure—Invertible Type



Key
1 drain valve
2 drain slope 5º
3 levels
4 level cover
5 gauge mounting
6 rolled bead
7 top cone pitch 25º
8 reinforcing bands
9 bottom cone pitch 20º
10 adjustable legs

Figure 2—Field Standard Test Measure—Bottom Drain Type

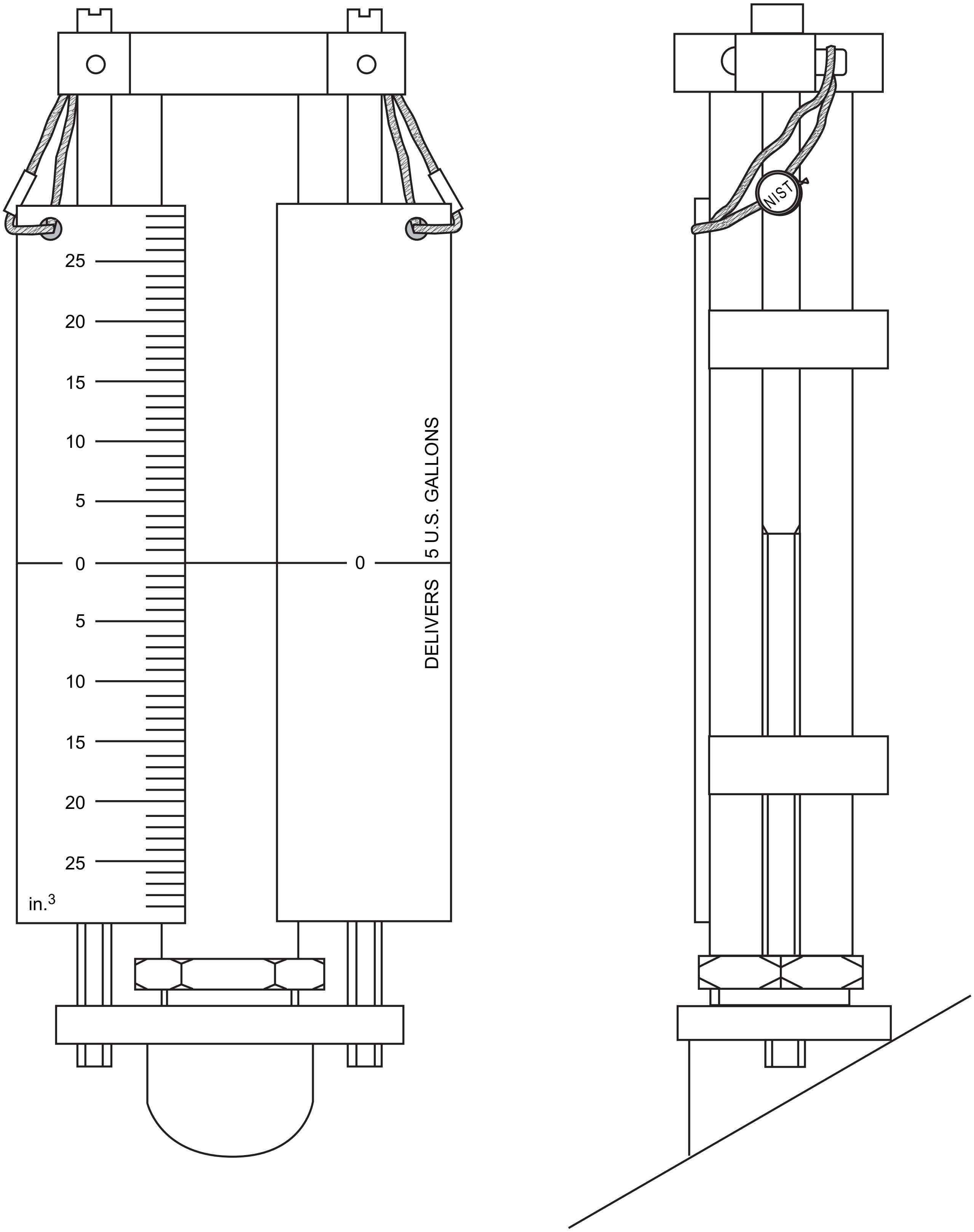


Figure 3—Gauge Glass and Scale Assembly

The drain valve shall be a quick-acting full-port valve, open ended for visual inspection, or shall have a visual-inspection device immediately downstream of the valve to detect valve failure. All drain valves shall have the capability of being sealed prior to calibration of the test measure. This valve shall be leak-free at all times. Uniquely numbered seals shall be affixed at the calibration agency with corrosion-resistant stainless steel wire to provide positive proof that the drain valve has not been replaced or serviced since calibration. Minimum drain sizes are described in NIST Handbook 105-3, Table 1a and Table 1b.

Certain flanged type valves are designed to allow replacement of internal parts without affecting the calibrated volume of the test measure. If internal parts are replaced or maintenance is performed on these valve types, the original seal from the calibration agency may be replaced if agreed upon by witnessing parties. This change shall be documented and becomes an additional part of the original calibration report until recalibrated by the appropriate agency.

A test-measure drain is described as a gravity discharge line between the bottom of the bottom cone and the shut-off valve. It shall have a downward slope of at least 5° from the horizontal plane. All pipes connected to the test-measure drain line, downstream of the shut-off valve, shall be positioned at an elevation to ensure the complete emptying of the test measure.

4.5 Levels and Leveling

All bottom-drain test measures that are not in a permanent installation shall have a minimum of three adjustable legs that enable the test measure to be leveled.

All bottom-drain field standard test measures should be equipped with a minimum of two adjustable spirit levels, mounted at right angles to each other, or with equivalent leveling indicator(s) on the upper cone in a protected position on the side of the vessel.

A precision level should be used to verify the permanently mounted spirit levels. If the precision and spirit levels show different level indications, then two vertical level measurements of the neck will be made with a precision level to adjust the test measure to a level position. One of the level indications will be made in line with the neck scale and the other 90° to that indication.

Spirit levels should be verified or adjusted to the vertical neck level measurements prior to shipment to NIST for calibration. Spirit levels are not sealed at NIST.

For all top-drain field standard test measures, the test measure shall be placed on a level flat metal plate for scale readings. The metal plate shall remain level in two perpendicular horizontal orientations during the calibration.

4.6 Scale Plate and Graduations

The scale plate shall be made of corrosion-resistant metal and shall be mounted tangent to the front of the gauge glass. It shall not be more than 0.25 in. (6 mm) from the glass.

Scale numbering on all field standard test measures shall be specified on the scale in milliliters (ml), cubic inches (in.^{3}), or other volume units. The units of measurement should be clearly marked on the scale. To avoid confusion and possible errors in reading, dual numbering on any one scale (e.g. cubic inches and decimal fractions of a gallon) is not permitted. Dual numbering is permitted only if two scale plates are used; in this case, the USC units scale (in.^{3}) is preferred and located on the left when the test measure is viewed from the front.

It is recommended that the metric scale (ml) be installed on the right side of the gauge glass. Provisions shall be made allowing either scale to be adjusted individually so that the two zero lines are in the same vertical position.

Scales shall be graduated both above and below the zero line. For neck sizes smaller than 17 in. (43 cm) in diameter, every fifth line on the scale shall be considered a major division and shall be longer than the intermediate or subdivision lines. Every major line shall be numbered with the volume to that mark. For neck diameters of 17 in.

(43 cm) or larger, every 10th line may be designated a major division line. For small-diameter, high-sensitivity measures that have diameters of 2 in., 3 in., or 4 in. (5 cm, 7 1/2 cm, or 10 cm), every fourth or fifth division is a major numbered division depending upon the scale increments.

A sufficient number of scale brackets (a minimum of two) shall hold the scale plate rigid. The brackets shall be mounted on adjusting rods.

An adjusting rod shall be provided with a means for sealing that will prevent movement. The scale plate shall be securely attached to the brackets and provided with a means for sealing. Movement of the adjusting mechanism or scale plate shall not be possible without breaking the seal. All seals should be affixed with corrosion-resistant Series 316 stainless steel or equivalent wire.

The graduation lines, numbers, and other information on the scale plate shall be permanent. Graduation lines shall be of uniform width. The width of the lines shall be no more than 0.025 in. (0.6 mm) or less than 0.015 in. (0.4 mm). The distance between scale graduations shall not be less than 0.0625 in. (2 mm).

On scale plates mounted to the front of the gauge glass, the major (numbered) lines shall be at least 0.25 in. (6 mm) in length. The intermediate lines shall be at least 0.125 in. (3 mm) in length. The major and intermediate lines shall extend to the edge of the scale plate nearest the gauge glass. The zero line shall extend completely across the plate.

On a scale plate mounted behind the gauge glass, the major (numbered) lines shall be at least 0.750 in. (19 mm) in length. Intermediate lines shall be at least 0.50 in. (13 mm) in length. The zero line shall extend completely across the plate.

Two commercially-available classes of test measures are designated normal sensitivity and high sensitivity. Uncertainty in the calibration is different for each class of the same size test measure. This is due to the improved scale sensitivity and the repeatability of the smaller-diameter neck in the high-sensitivity test measures. Scale graduations for normal-sensitivity test measures are listed in Table 1. Scale graduation for high-sensitivity test measures are listed in Table 2.

4.7 Nameplate

Each field standard test measure shall bear in a conspicuous place the name of the manufacturer, the nominal volume, and a serial or identification number. The material from which the standard is constructed shall be shown together with its cubical coefficient of thermal expansion per °F (or °C) for that material.

Table 1—Scale Graduations for Normal-sensitivity Test Measures

Nominal Gallon Size	**Neck Diameter** (in.)	**Minimum Number of in.^{3} Above and Below 0**	**Minimum Discrimination Between Graduations** (in.^{3})	**Maximum Scale Spacing** (in.)
1	3 7/8	15	1	0.085
5	3 7/8	15	1	0.085
10	3 7/8	30	1	0.085
25	5	60	2	0.102
50	5	120	2	0.102
100	7	250	5	0.130
200	10	500	10	0.127
500	17	1250	25	0.110

Table 2—Scale Graduations for High-sensitivity Test Measures

Nominal Gallon Size	Neck Diameter (in.)	Minimum Number of in.^{3} Above and Below 0	Minimum Discrimination Between Graduations (in.^{3})	Maximum Scale Spacing (in.)
1	2	20	$^1/_4$	0.080
5	2	20	$^1/_4$	0.080
10	2	20	$^1/_4$	0.080
25	3	35	$^1/_2$	0.071
50	3	50	$^1/_2$	0.071
50	4	50	1	0.080
100	4	50	1	0.080

4.8 Handling

A field standard test measure is a precision instrument and shall be handled with great care to avoid damage that may alter its volume. Any test measure that is normally transported to various locations should be protected. A case, shipping container, or other means that sufficiently protects the test measure against dents and/or scale damage during storage or transportation should be used. Test measures mounted and moved on trailers should be secured to prevent movement or damage during travel.

5 Inspection and Cleaning

5.1 General

All test measures shall be inspected and cleaned prior to calibration. Inspections or examinations are required for new test measures and prior to each calibration.

5.2 Visual Inspection

A visual inspection of any field standard test measure shall be made before each calibration to ascertain that the capacity has not been altered by dents, internal corrosion or surface deposits. In addition, the test measure shall be inspected carefully to make sure it is free of rust, broken seals, broken gauge glasses or scales, leaks, or defective drain valves.

Interior joints and seams shall be smooth and uniform. Surfaces, including joints and seams, shall be clean and free from grease, dirt, or oil film. Surfaces shall be smooth and free from rust corrosion. Potential air or water traps, resulting from either design or damage, are not permitted.

The interior of test measures should never be exposed to salt water or other type of water with a high concentration of dissolved solids. Isolated use of contaminated water in a test measure may cause corrosive damage, pitting, and/or deposits to adhere to the interior surfaces.

Noninvertible test measures shall be equipped with a fixed anti-swirl plate to eliminate the formation of a vortex during draining.

The neck on a test measure shall be uniformly cylindrical throughout the length of the neck. The top surface of the neck of a test measure shall be ground, machined, or smoothly formed.

The scale shall be of corrosion-resistant metal, firm, secure, and easily adjustable. A provision shall exist for affixing a stainless wire seal to provide a means for detecting unauthorized adjustment. The scale divisions or graduations shall be linear. The scale length shall be appropriate to the test measure. Applicable volume units (cubic inches, milliliters, gallons, liters, or others) shall be clearly indicated, and scale markings shall be legible.

The gauge glass shall be clean and clear after wetting (that is, no droplets should be present), and it shall be capable of being removed, cleaned, and replaced.

5.3 Cleaning Procedures

Prior to any cleaning of a test measure, it should be examined for any signs of damage as described in the inspection section. Normal cleaning of the interior of the test measure involves scrubbing with a biodegradable detergent and water. However, if the interior of the test measure contains oil residue then it may be necessary to use solvents for cleaning prior to cleaning with detergents.

In the event a test measure is heavily contaminated with oil residues, the additional step of steam cleaning the interior of the test measure prior to any solvent cleaning or detergent washing may be required. Once the test measure has been cleaned, it should be rinsed and allowed to dry.

6 Calibration

6.1 General

The National Institute of Standards and Technology (NIST) is the calibrating agency of choice in the United States for field standard test measures used to calibrate meter provers.

Calibrations shall be in accordance with NIST SP 250-72, using pure water (distilled, de-ionized or reverse osmosis source with a maximum conductivity of 2 μS) as the calibrating liquid. This standard dictates reference water shall be used as the calibrating liquid because of its stability, low thermal coefficient of expansion, and high heat capacity. The actual *delivered volume* of the test measure shall be used as the official capacity used to calibrate provers.

6.2 Calibrated Volume

Test-measure calibrations can determine contained volume or delivered volume. A field standard test measure can be designed and built to contain a precise liquid volume when filled from a clean, empty, and dry condition. Test measures calibrated for “contained volume” have a specified volume that is not used in prover calibrations, because the “empty” condition means empty, clean, and dry before every use, usually an impractical field operations requirement.

Test-measure-delivered volumes are used to calibrate provers. Preparing the test measure for calibration use requires that it is wetted prior to use. It should be filled with water to its zero mark, leveled, and then drained exactly for the prescribed draining time as given on the report of calibration. The test measure is then returned to an upright position or its drain valve is closed leaving it with a controlled and repeatable amount of clingage (water) inside prior to use. To ensure that this clingage quantity is repeatable means that the test measure shall be completely filled, and then emptied, in strict compliance with the operating procedures and draining times that are specified on its calibration report. Just wetting the interior of the test measure prior to use is completely unacceptable.

The prescribed draining time for all test measures calibrated by NIST and drained by inverting, is currently 10 s after the cessation of main flow. Similarly, the draining time for all NIST calibrated test measures having bottom drains is currently 30 s after the cessation of main flow. The drain time to be used is stated on each “Report of Calibration.”

On some occasions, the same test measure may be calibrated by two or more different NMIs for use in different countries. For example, NIST and the Canadian Standards Agency (CSA) may both calibrate the same test measure. Similarly, on occasions the same test measure can be calibrated in different units of measurement. For example, the test measure may be calibrated in both milliliters (ml) and cubic inches (in.^{3}). This will require that two different reports of calibration, developed either by the same calibrating agency, or by two different agencies, be issued. Units of measurement, test measure volumes, and required drain times shall all be followed exactly for the specific report of calibration being used. No interchanging of data (volumes, units of measure, drain times) or other information between two different reports of calibration for the same test measure is permitted.

6.3 Calibration Frequency

6.3.1 General

All field standard test measures to be used for prover calibrations in the United States shall have a "Report of Calibration," issued by NIST. The report shall be within the last five years (not to exceed five years). A test measure's recalibration volume will be evaluated in accordance with Annex A.

6.3.2 Recalibration

Test measures shall be calibrated any time there is evidence of damage, distortion, repairs, alterations, or maintenance to the test measure or replacement of the drain valve that could affect its volume or its use.

A test measure shall be recalibrated prior to continued use if any of the following occur:

— the NIST seal on the scale is broken or tampered with in any manner;

— any damage to the neck, main body or top/bottom of the main body occurs;

— the seal on the bottom drain valve is broken or tampered with in any manner, unless as provided for in 4.4;

— the scales on the neck are broken or tampered with in any manner;

— any threaded connections within the calibrated volume area (i.e. thermowells) are damaged, leaking or tampered with in any manner.

6.4 Number of Calibration Runs

A minimum of five measurements of volume shall be made to assess the repeatability of the process and the test measure.

6.5 Seals

After calibration, NIST shall affix a tamper proof seal on the adjustable scale and drain valve.

6.6 Disputes

In the case of a dispute between interested parties over the accuracy of a test measure, the disputed test measure shall be submitted to NIST for final judgment of its accuracy.

7 Calibration Methods

7.1 General

Calibrations shall be in accordance with procedures of NIST SP 250-72, or the procedures of a National Metrology Institute (NMI) that all interested parties agreed upon.

Three methods are used to calibrate test measures at NIST. They vary depending upon test measure size. The methods are:

— for measures 1 gal to 100 gal, the direct-weighing gravimetric method;

— for measures over 100 gal to 500 gal, the gravimetric transfer method (pre-weighed water);

— for measures larger than 500 gal, the volume transfer method.

In the direct-weighing method, the test measure is placed directly on a scale. The measure is filled, weighed and emptied multiple times. The net mass and the temperature of the water are determined for each fill of the test measure. The average volume of the test measure is determined from a minimum of at least five fills of the test measure.

The gravimetric transfer (pre-weighed water) method is performed on measures that are too large for direct weighing on the scale. Water is weighed in a container smaller than the test measure. The water is then drained from the container into the test measure. Several transfers of water are made to the test measure to determine its volume. The net mass transferred to the measure and the water temperature in the test measure being calibrated is recorded. The average volume of the test measure is determined from a minimum of at least five complete fills of the test measure.

For large-volume test measures, the volume transfer method is used. A smaller calibrated test measure of the agency's choice is used for the reference measure. It is filled numerous times and emptied into the measure being tested. The total volume transferred is determined and used as the volume of the measure under test.

The detailed procedures and calculations of each method can be found in NIST SP 250-72.

7.2 Documentation

Documentation shall be available to all persons who have custody transfer interests in the test measure. This documentation shall include the manufacturer's identification of the construction material, current report of calibration, calibration data and calculations for the current delivered volume, historical control chart for all calibrations, detailed drawings or pictures to identify imperfections in the test measure at the time of calibration, and any other documents deemed relevant to the current volume. Control charts and identification pictures are included in the NIST report (see Annex B).

The test measure owner shall maintain a calibration and repair history. All documents related to a measure's history should be available upon request to any interested party with interest in the prover being calibrated.

8 Operations and Use

8.1 Primary Use

The primary use of field standard test measures is to determine the volume of a meter prover when using the waterdraw method of calibration. Only test measures calibrated with a delivered volume shall be used in the calibration of meter provers.

8.2 Field Use of Volumetric Test Measures

Field standard test measures are used in the waterdraw calibration of displacement provers, and tank provers. Full descriptions on the field use of these test measures are found in API *MPMS* Chapter 4.9.2, *Determination of the Volume of Displacement and Tank Provers by the Waterdraw Method of Calibration*. The procedure for calculating the base volume of a displacement or tank prover, using field standard test measures, is described in API *MPMS* Chapter 12.2.4, *Calculation of Base Prover Volumes by the Waterdraw Method*.

Annex A
(informative)

Calibration Frequency of Test Measures

Historically, calibration frequencies were not defined in industry standards. The industry implemented a frequency of three years for most test measures based upon best practices and not on test measure calibration stability (performance).

In recent years, the certification of test measures has been greatly improved due to:

— improved communications between NIST and the petroleum industry,

— improved calibration laboratory facilities,

— direct mass calibration of test measures up to 100 gal,

— gravimetric transfer calibration of test measures over 100 gal to 500 gal,

— improved test measure uncertainty by implementing five run calibrations,

— improved calculations for laboratory uncertainty analysis,

— NIST providing historical control charts,

— digital methodology allows for the instantaneous verification of calibration results.

A review of the historical data indicates that a majority of recalibrations agree with NIST expectations. Those expectations are based upon the uncertainty of the calibration process. Additionally, when frequency was extended to five years there was no indication of an increase in the number of measures that do not meet these expectations. Therefore, for this standard, the recalibration frequency has been extended from three years to five years.

NIST and the industry have partnered to develop a methodology to evaluate a test measure's volume changes. This evaluation is based on historical calibration data for the test measure and the "degree of equivalence (E_n)."

Degree of equivalence (E_n) is used to indicate whether or not two measurements agree relative to the uncertainty of the individual measurements. In the context of this standard, E_n is used to indicate whether the difference between two NIST volume measurements for a particular test measure is larger than would be expected given the uncertainty of the calibration (at the 95 % confidence level).

The basis for performance evaluation follows a simplified version of the calculations recommended for laboratory comparisons by Cox [2]. The procedure is as follows.

1) Calculate the difference between the two volume calibrations: $\Delta V = V_i - V_{i-1}$.

2) Calculate the expanded uncertainty for this difference: $U(\Delta V) = \sqrt{2}\, u_e\,(V_{\mathrm{NIST}})$, where $u_e(V_{\mathrm{NIST}})$ is the expanded ($k = 2$, approximately 95 % confidence level) uncertainty of the volume calibration performed at NIST. [3]

[2] Cox, M. G., "The Evaluation of Key Comparison Data," *Metrologia*, 2002, Vol 39, pp 589 – 595.

[3] Step 2 is a simplification of Cox Equation 2, Equation 4, and Equation 5 for the uncertainty of the degree of equivalence with equal uncertainties for the calibrations assumed and $N = 2$.

3) Check whether the calibration difference can be accounted for by its expanded uncertainty:

$$E_n = \left|\frac{\Delta V}{U(\Delta V)}\right| < 1 \text{, i.e. } |\Delta V| > \sqrt{2}\, u_e\, (V_{\mathrm{NIST}}).$$

Given no physical changes in the test measure and a good estimate of the expanded uncertainty for the calibrations at the 95 % confidence level, values of $E_n > 1$ should only occur for about 5 % of the cases in a population. Hence, $E_n > 1$ can be used as a trigger for investigation into:

1) whether the volume of the test measure has changed due to a valve change, a dent, repositioning of the neck scale, or other reasons; or

2) whether an error was made in the volume measurement process.

The calibration NMI should report the degree of equivalence (E_n) value for test measures used to calibrate provers. When E_n is greater than one (1), the institute should investigate possible reasons for the volume change. If the change is not the result of a physical change, the institute should confirm that the volume measurement process by recalibrating one of their volume check standards. The NMIs typically have an extensive history on their check standards. The process of recalibrating one of those standards will verify the current process (volume in question) is valid. The validation of the current process is confirmed when recalibration of the check standard results in a volume that is within the uncertainty of that standard. The results of the investigation should be reported to the owner of the test measure and become part of the measure's documentation.

Annex B
(informative)

Example of NIST Report of Calibration for Field Standard Test Measure

Where applicable, authorities having jurisdiction should be consulted.

National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

REPORT OF CALIBRATION

FOR

A ONE HUNDRED (100) GALLON GRADUATE VOLUME PROVER
(Graduated Neck Type)

September 23, 2008

Manufacturer: Test Measure Co.
Anywhere, MD

NIST Seal Number: 1234
Material: Stainless Steel
Serial Number: ABC123

submitted by

Test Measure Co.
123 West St.
Anywhere, MD 20202

(Reference: Purchase Order Number XYZ1008, September 1, 2008)

The internal volume of the prover described above has been determined by the gravimetric method [1]. The gravimetric method requires weighing the vessel dry and empty and re-weighing it when filled with a fluid of known density. The internal or contained volume was determined in this way and the value is given in Table 1 using the requested units. The fluid used was distilled water and the prover was leveled before determining the volume.

To determine the delivered volume, the contained volume is poured from the prover by opening the valve at the bottom of the vessel. When this flow finishes, the valve is held open for 30 seconds to complete the drain procedure. Subsequent re-weighing completes the gravimetric procedure and enables calculation of the delivered volume, also given in Table 1. Both the contained and delivered volumes are given for the scale reading of zero (0) and have been corrected for the reference temperature of 15.56 °C (60 °F) assuming a volumetric coefficient of expansion of 0.0000477 per °C (0.0000265 per °F).

[1] Bean, V. E., Espina, P. I., Wright, J. D., Houser, J. F., Sheckels, S. D., and Johnson, A. N., "NIST Calibration Services for Liquid Volume," NIST Special Publication 250-72, National Institute of Standards and Technology, March 24, 2006.

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Table 1. Contained and delivered volumes for the tested vessel for a scale reading* of zero.

	Volume Contained	Volume Delivered
gal at 60 °F	100.0253	**100.0007**
in^3 at 60 °F	23105.85	**23100.18**

The volume measurement procedure was repeated 5 times with the neck scale filled approximately to zero each time. The repeatability of the 5 measurements was 18 parts in 10^6 and the expanded uncertainty in the measured volume is ±0.007 %. It was calculated according to References [1] and [2] with a 95 % confidence level† and is traceable to NIST mass, temperature, pressure, and humidity standards, and a NIST distilled water density determination.

Figure 1. Photographs of the volume prover.

* The scale reading is determined by the intersection of the horizontal plane, tangent to the bottom of the meniscus reading on the gauge tube. For this vessel, the scale range was from –130 and +160 and each division is equivalent to 2 in^3.

[2] Taylor, B. N. and Kuyatt, C. E., "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," NIST Technical Note 1297, National Institute of Standards and Technology (January 1993).

† Coverage factor of 2.26 for 9 effective degrees of freedom.

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The input data used for calculation of the prover volume are given in the spreadsheet attached to this report.

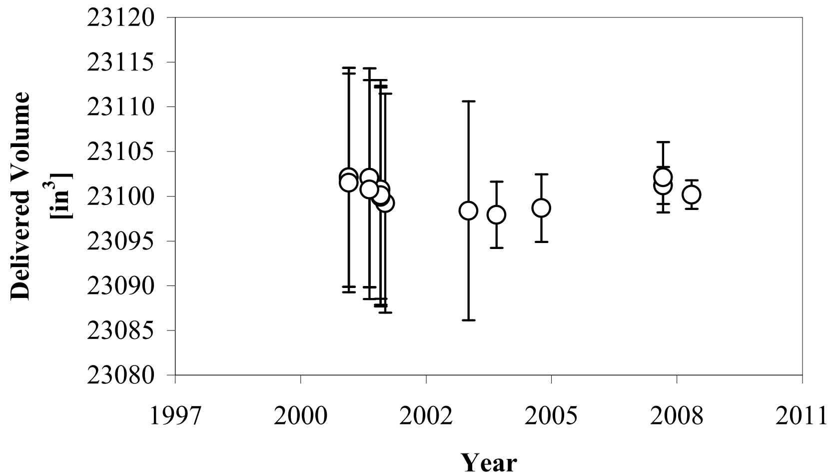

Figure 2. Calibration control chart for 100 gallon graduated neck test measure SN ABC123.

Table 2. Results of prior calibrations for the delivered volume.

Date	Delivered Volume [in^3]	Difference from Prior [in^3]	Degree of Equivalence [-]
09/24/08	23100.18	-1.02	-0.17
02/12/08	23101.20	-0.92	-0.16
02/12/08	23102.12	3.44	0.58
06/15/05	23098.68	0.76	0.13
06/23/04	23097.92	-0.46	-0.08
11/13/03	23098.38	-0.84	-0.14

For the Director,
National Institute of Standards and Technology

Dr. John Doe
Project Leader, Calibration Dept
Test Measure Co.

Jane Doe
Calibration Technician
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