Manual of Petroleum Measurement Standards Chapter 12—Calculation of Petroleum Quantities

Section 2—Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors

Part 4—Calculation of Base Prover Volumes by the Waterdraw Method

FIRST EDITION, DECEMBER 1997

Reaffirmed 3/2002

American
Petroleum
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FOREWORD

This five-part publication consolidates and presents standard calculations for metering petroleum liquids using turbine or displacement meters. Units of measure in this publication are in International System (SI) and United States Customary (USC) 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 and the Gas Processors Association.

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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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PART 4—CALCULATION OF BASE PROVER VOLUMES BY THE WATERDRAW METHOD

1 Purpose

When most of the older standards were written, mechanical desk calculators were widely used for calculating measurement documentation, and tabulated values were used more widely than is the case today. Rules for rounding and the choice of how many figures to enter in each calculation step were often made on the spot. As a result, different operators obtained different results from the same data.

This five-part publication consolidates and standardizes calculations pertaining to the metering of petroleum liquids, using turbine or displacement meters, and clarifies terms and expressions by eliminating local variations of such terms. The purpose of standardizing the calculations is that all parties will produce the same unbiased answer from the given data. To obtain identical results from the same data, the rules for rounding, sequence, and discrimination of numbers (decimal places) have all been defined.

2 Scope

This document provides standardized calculation methods for the quantification of liquids and the determination of base prover volumes under defined conditions, regardless of the point of origin or destination or units of measure required by governmental organizations. The criteria contained in this document allows different individuals, using various computer languages on different computer hardware (or manual calculations), to arrive at identical results using the same standardized input data.

This publication rigorously specifies the equations for computing correction factors, rules for rounding, the sequence of the calculations, and the discrimination levels of all numbers to be used in these calculations. No deviations from these specifications are permitted since the intent of this document is to serve as a rigorous standard.

3 Application of Part 4

For custody transfer and fiscal applications, provers are defined as field transfer standards used to calibrate flow meters for the purpose of correcting their indicated volumes.

The Base Prover Volume (BPV) of a displacement prover may be determined by several different procedures, two of which are the waterdraw method and the master meter method. *This standard only discusses the calculation procedures for the waterdraw calibration method.*

The purpose of standardizing terms and arithmetical procedures employed in calculating the base prover volume is to avoid disagreement between the parties involved in the facility. The purpose of Part 4, "Calculation of Base Prover Volume By Waterdraw Method," is to obtain the same unbiased answer from the same measurement data, regardless of who or what does the computing. The result of these efforts is to produce a certified prover volume.

A Calibration Certificate serves as the document that states the Base Prover Volume (BPV) and also reports the physical data used to calculate that base prover volume.

Operational procedures used to calibrate a prover are specified in different sections of API MPMS Chapter 4—Proving Systems.

4 Organization of Standard

This standard has been organized into five separate parts. Part 1 contains a complete general introduction to dynamic measurement calculations. Part 2 focuses on the calculation of metered quantities for measurement tickets. Part 3 applies to the calculation of meter factors in proving operations and proving reports. Part 4 applies to the determination of base prover volumes by the waterdraw method, and Part 5 describes the calculation steps required to determine a Base Prover Volume (BPV) by the master meter method.

4.1 PART 1—INTRODUCTION

The base (reference or standard) volumetric determination of metered quantities is discussed along with the general terms required for the solution of various equations.

General rules for rounding of numbers, field data and intermediate calculation numbers, and discrimination levels, are all specified within the context of this standard.

For the proper use of this standard, a discussion is presented on the prediction of the density of a liquid at both flowing and base conditions.

An explanation of the principal correction factors associated with dynamic measurement are presented in a clear and concise manner.

4.2 PART 2—MEASUREMENT TICKETS

The application of this standard to the calculation of metered quantities is presented for base volumetric calculations in conformance with North American industry practices.

Recording of field data, rules for rounding, calculation sequences and discrimination levels are specified, along with a set of example calculations. The examples are designed to aid in checkout procedures for any routines that are developed using the requirements stated in this part.

4.3 PART 3—PROVING REPORTS

The application of this standard to the calculation of proving reports is presented for base volumetric calculations in conformance with North American industry practices. Proving reports are utilized to calculate the following meter correction and/or performance indicators: Meter Factors (MF), Composite Meter Factors (CMF), K Factors (KF), Composite K Factors (CKF), and Meter Accuracy Factor (MA). The determination of the appropriate term is based on both the hardware and the preference of the user.

Recording of field data, rules for rounding, calculation sequences and discrimination levels are specified, along with a set of example proving calculations. The examples are designed to aid in checkout procedures for any routines that are developed using the requirements stated in this part.

4.4 PART 4—CALCULATION OF BASE PROVER VOLUMES BY THE WATERDRAW METHOD

The waterdraw method uses the drawing (or displacement) of water from the prover into certified volumetric field standard test measures. For open tank provers, the waterdraw method may also employ the displacing (or drawing) of water from the certified field standard test measures into the tank prover. This is sometimes referred to as the waterfill method. Certification of all field standard test measures must be *traceable* to an appropriate national weights and measures organization.

Recording of field data, rules for rounding, calculation sequences and discrimination levels are specified, along with a set of example calculations. The examples are designed to aid in checkout procedures for any routines that are developed using the requirements stated in this section.

4.5 PART 5—CALCULATION OF BASE PROVER VOLUMES BY THE MASTER METER METHOD

The master meter method uses a transfer meter (or transfer standard). This transfer meter is proved under actual operating conditions, by a prover which has been previously calibrated by the waterdraw method, and is designated the master meter. This master meter is then used to determine the base volume of a field displacement prover.

Recording of field data, rules for rounding, calculation sequences and discrimination levels are specified, along with a set of example calculations. The examples are designed to aid in checkout procedures for any routines that are developed using the requirements stated in this part.

5 Referenced Publications

Several documents served as references for the revisions of this standard. In particular, previous editions of API MPMS Chapter 12 provided a wealth of information. Other publications which served as a resource of information for this revision are:

API
- *Manual of Petroleum Measurement Standards* (MPMS)
  - Chapter 4—"Proving Systems"
  - Chapter 5—"Metering"
  - Chapter 6—"Metering Assemblies"
  - Chapter 7—"Temperature Determination"
  - Chapter 9—"Density Determination"
  - Chapter 11—"Physical Properties Data"
  - Chapter 13—"Statistical Aspects of Measuring and Sampling"

NIST[1]
- Handbook 105-3 "Specifications and Tolerances for Reference Standards and Field Standards"
- Monograph 62 "Testing of Metal Volumetric Standards"

6 Field of Application

6.1 APPLICABLE LIQUIDS

This standard applies to liquids that, for all practical purposes, are considered to be clean, single-phase, homogeneous, and Newtonian at metering conditions. Water meets all of these requirements. Specifically, the waterdraw method displaces (or draws) water from the prover into certified volumetric field standard test measures.

Therefore, the application of this standard shall be limited to water, which is assumed to be clean, air/gas free, and which utilize tables together with implementation procedures, to correct metered volumes at flowing temperatures and pressures to corresponding volumes at base (reference or standard) conditions. To accomplish this, the density correlations for water are specified in API MPMS Chapter 12.2 Part 1—Introduction, Appendix B.

[1]U.S. Department of Commerce, National Institute of Standards and Technology, Washington, D.C. 20234 (formerly the National Bureau of Standards).

6.2 BASE CONDITIONS

Historically, the measurement of liquids for custody transfer and process control has been stated in volume units at base (reference or standard) conditions.

Base conditions for the measurement of liquids, such as crude petroleum and its liquid products, having a vapor pressure equal to or less than atmospheric pressure at the base temperature are:

United States Customary (USC) Units:
Pressure—14.696 psia (101.325 kPa)
Temperature—60.0°F (15.56°C)

International System (SI) Units:
Pressure—101.325 kPa (14.696 psia)
Temperature—15.00°C (59.0°F)

For liquid applications, base conditions may change from one country to the next. Therefore, it is necessary that the base conditions be identified and specified in all standardized volumetric flow measurements by all the parties involved in the measurement.

7 Precision, Rounding, and Discrimination Levels

The minimum precision of the computing hardware must be equal to or greater than a ten digit calculator to obtain the same answer in all calculations. All the calculations shall be performed serially, in the order specified, and rounding shall only take place after the final value in an equation has been determined.

General rounding rules and discrimination levels are described in the following subsections.

7.1 ROUNDING OF NUMBERS

When a number is to be rounded to a specific number of decimals, it shall always be rounded off in one step to the number of figures that are to be recorded, and shall not be rounded in two or more steps of successive rounding. The rounding procedure shall be in accordance with the following:

a. When the figure to the right of last place to be retained is 5 or greater, the figure in the last place to be retained should be increased by 1.
b. If the figure to the right of the last place to be retained is less than 5, the figure in the last place retained should be unchanged.

7.2 DISCRIMINATION LEVELS

For field measurements of temperature and pressure, the levels specified in the various discrimination tables are the maximum levels.

Some examples of recording acceptable discrimination levels are as follows:

a. If the parties all agree to use "smart" temperature transmitters which can indicate temperatures to 0.01°F or 0.005°C, then the reading shall be rounded and recorded to XX.X°F or XX.X5°C value prior to recording for calculation purposes.
b. If the parties agree to use a mercury in glass thermometer with increments of 0.2°F or 0.10°C, then the reading shall be recorded and rounded as XX.X°F or XX.X5°C for purposes of the calculations.

8 Definitions and Symbols

The definitions and symbols described below are relevant in applying Part 4—Calculation of Base Prover Volumes by the Waterdraw Method.

8.1 DEFINITIONS

8.1.1 barrel (bbl): A unit of volume equal to 9,702.0 cubic inches, or 42.0 U.S. gallons.

8.1.2 U.S. gallon (gal): A unit of volume equal to 231.0 cubic inches.

8.1.3 cubic meter (m^3): A unit of volume equal to 1,000,000.0 milliliters (ml), or 1,000.0 liters. One cubic meter equals 6.28981 barrels.

8.1.4 liter (l): A unit of volume equal to 1,000.0 milliliters (ml) or 0.001 cubic meters.

8.1.5 pass: A single movement of the displacer between detectors which define the calibrated volume of a prover.

8.1.6 round-trip: The combined forward (out) and reverse (back) passes of the displacer in a bidirectional prover.

8.1.7 field standard test measure: A vessel (usually of stainless steel), fabricated to meet rigorous design criteria and specification, that is used as the basic standard of measurement in the waterdraw calibration of volumetric provers. After calibration by a National Standards Agency, the field standard test measure is used to determine the base volume of the prover under test.

8.1.8 run, prover calibration: One pass of a unidirectional prover or one round trip of a bidirectional prover, or one emptying or filling of a volumetric prover tank, the result of which is deemed acceptable to provide a single test value of the Calibrated Prover Volume (CPV).

8.1.9 calibrated prover volume (CPV): The volume at base conditions between the detectors in a unidirectional prover, or the volume of a prover tank between specified "empty" and "full" levels, as determined by a single calibration run. The Calibrated Prover Volume (CPV) of a bidirectional prover is the sum of the two volumes swept out between detectors during a calibration round-trip.

8.1.10 targeted BPV: A term associated with Open Tank Prover calibration, refers to adjusting the scales to an even nominal value, such as 500 gallons, or 1,000 gallons. For load rack applications, open tank provers are adjusted to arrive at exactly the Targeted BPV value.

8.1.11 calibration certificate: A document stating the Base Prover Volume (BPV) and the physical data used to calculate that base prover volume (e.g., *E*, *Gc*, *Ga*, *Gl*).

8.1.12 base prover volume: The volume of the prover at base conditions, as shown on the calibration certificate, and obtained by arithmetically averaging an acceptable number of consecutive Calibrated Prover Volume (CPV) determinations.

8.2 SYMBOLS

A combination of upper and lower case notation is used for symbols and formulas in this publication. Subscripted notation is often difficult to use for computers and other word processing documents, and therefore has not been used in this publication, but may, however, be employed if the interested parties wish.

Symbols have been defined to aid in clarity of the mathematical treatments. Notations at the end of a symbol such as "*tm*" always refer to the test measure, "*p*" always refers to the prover, and "*b*" refers to base conditions. Other additional letters have also been added to the symbolic notations below for clarity and specificity.

Units

SI	International System of units (Pascal, cubic meter, kilogram, metric system).
USC	US Customary units (inch, pound, cubic inch, traditional system).

Pipe Dimensions

ID	Inside diameter of prover.
OD	Outside diameter of prover.
WT	Wall thickness of prover.

Liquid Density

DEN	Density of the water in kilogram per cubic meter (kg/m^3) units.
DENb	Base density of water in kilogram per cubic meter (kg/m^3) units.
DENobs	Observed density of the water at base pressure in kilograms per cubic meter (kg/m^3) units.
RHOb	Base density of the water.
RHOp	Density of the water in prover (for prover calibrations).
RHOtm	Density of the water in test measure (for prover calibrations).

Temperature

°C	Celsius temperature scale.
°F	Fahrenheit temperature scale.
T	Temperature.
Tb	Base temperature, in °F or °C units.
Td	Temperature of detector mounting shaft or displacer shaft on small volume prover with external detectors.
Ttm	Temperature of water in test measure, in °F or °C.
Tp	Temperature of water in prover, in °F or °C.

Pressure

kPa	Kilopascals in absolute pressure units.
kPag	Kilopascals in gauge pressure units.
psi	Pounds per square inch (USC) pressure units.
psia	Pounds per square inch in absolute pressure units.
psig	Pounds per square inch in gauge pressure units.
P	Operating pressure in gauge pressure units.
Pb	Base pressure, in psi or kPa pressure units.
Pba	Base pressure, in absolute pressure units.
Pbg	Base pressure, in gauge pressure units.
Pp	Pressure of water in the prover, in gauge pressure units.
Pe	Equilibrium vapor pressure of water at operating conditions, in absolute pressure units.
Peb	Equilibrium vapor pressure of water at base temperature, in absolute pressure units.

Correction Factors

CPL	Basic correction for the compressibility of a liquid.
CPS	Basic correction for the pressure effects on steel.
CTL	Basic correction for the effect of temperature on a liquid.
CTS	Basic correction for the effect of temperature on steel.
CPLtm	Correction for compressibility of the water in test measure.
CPLp	Correction for compressibility of the water in prover.
CPStm	Correction for the effect of pressure on steel test measure.
CPSp	Correction for the effect of pressure on steel prover.
CTDW	Correction for the effect of the difference in temperature of the water between the prover and the test measure during the prover calibration.
CTStm	Correction for the effect of temperature on steel test measure.

CTSp	Correction for the effect of temperature on steel prover.
CCTS	Combined correction for effect of temperature on steel prover and steel test measure.
E	Modulus of elasticity of the steel prover.
F	Compressibility factor of water.
Fp	Compressibility factor of water in the prover.
Gl	Linear coefficient of thermal expansion.
Ga	Area coefficient of thermal expansion.
Gc	Cubical coefficient of thermal expansion of provers.
Gcm	Cubical coefficient of thermal expansion of test measure.

Volumes

BMV	Field Standard Test Measure base volume (from calibration certificate).
BMVa	Field Standard Test Measure base volume adjusted for the scale reading.
BPV	The base volume of the prover at standard conditions.
CPV	Calibrated prover volume as determined by a single calibration run.
SR	Scale reading of a field standard test measure.
SRu	Upper scale reading of an open tank prover.
SRl	Lower scale reading of an open tank prover.
WD	The base volume of the field standard test measure, adjusted for scale reading (*SR*), and corrected for *CTDW* and *CCTS*.
WDz	The sum of the *WD* values for all of the field standard test measures used in a single calibration pass of the prover.
WDzb	The *WDz* value for a single calibration pass corrected for *CPSp* and *CPLp*.

9 Calibration Requirements

The volume of each calibration pass shall be individually calculated to obtain a corrected volume at reference conditions. The calibration requirements are a function of the prover's design classification.

There are two general classes of liquid provers—displacement provers and open tank provers.

Sub-classes of displacement provers are unidirectional and bidirectional flow designs, as well as small volume provers which may also be of unidirectional or bidirectional construction.

Sub-classes of open tank provers are top filling or bottom filling designs with or without lower scales.

9.1 DISPLACEMENT PROVERS—UNIDIRECTIONAL DESIGN

For unidirectional provers, three or more consecutive passes are required for a calibration which shall meet the following criteria:

a. The calibration shall be considered acceptable when the prover volumes (*WDzb*) at reference conditions of three or more consecutive passes exhibit a range of 0.020 percent or less.
b. The flow rate between consecutive calibration passes shall have been changed by at least 25 percent or more.

Under certain circumstances, such as environmental conditions, if all parties concur, the flowrate change between consecutive runs may be waived. However, the flowrate between all consecutive runs must have a range of at least 25 percent. *Most important, the uncertainty associated with this exception is inferior to the preferred method stated above.*

9.2 DISPLACEMENT PROVERS—BIDIRECTIONAL DESIGN

For bidirectional provers, three or more consecutive roundtrips are required for a calibration and shall meet the following criteria:

a. The volume at reference conditions (*WDzb*) for the forward "out" pass for three or more consecutive roundtrips shall exhibit a range of 0.020 percent or less.
b. The volume at reference conditions (*WDzb*) for the reverse "back" pass for three or more consecutive roundtrips shall exhibit a range of 0.020 percent or less.
c. The Calibrated Prover Volume (CPV) for three or more consecutive roundtrips shall exhibit a range of 0.020 percent or less.
d. The flowrate between the "out" pass and the "back" pass must remain the same for each roundtrip.
e. The flow rate between consecutive roundtrips shall be changed by at least twenty five percent (25 percent) or more.

Under certain circumstances, such as environmental conditions, if all parties concur, the flowrate change between consecutive runs may be waived. However, the flowrate between all consecutive runs must have a range of at least 25 percent. *Most important, the uncertainty associated with this exception is inferior to the preferred method stated above.*

9.3 OPEN TANK PROVERS

For open tank provers, the calibration shall be considered acceptable when the following criteria are satisfied:

a. The Calibrated Prover Volumes (CPV) for two or more consecutive runs shall exhibit a range of 0.020 percent or less.
b. After adjusting the scale(s) and resealing, an additional calibrated volume at reference conditions must be determined. This volume must be within ±0.010 percent of the previously established targeted Calibrated Prover Volume (CPV).

9.4 REPEATABILITY

As a measure of repeatability, the following equation shall be utilized to calculate and verify the range results for all displacement, small volume and open tank provers:

$$\text{Range (\%)} = \frac{(\text{Max. Volume} - \text{Min. Volume})}{(\text{Min. Volume})} \times 100$$

10 Correction Factors

Calculations in this publication are based on determining the base volume of a prover by the waterdraw method. Corrections are made for:

a. The effects of thermal expansion of the water in the test measures and the prover.
b. The effects of thermal expansion of the steel in the test measures and the prover.
c. The compressibility of the water in the prover under calibration due to pressure.
d. The elastic distortion of the prover under calibration due to pressure.

Corrections for the temperature effects on the steel prover and test measures are combined and discussed in the following sections.

10.1 WATER DENSITY CORRECTION FACTORS

Water density correction factors are employed to account for changes in density due to the effects of temperature and pressure. These correction factors are:

CTDW corrects for the effect of water density changes due to temperature differences between the prover and the test measure.
CPL corrects for the effect of compressibility on the water density.

In using the waterdraw technique, clean, fresh water is required to properly utilize the thermal expansion (*CTL*) and compressibility (*CPL*) terms.

10.1.1 Correction for Effect of Temperature on Water Density (*CTDW*)

If water is subjected to a change in temperature (above 40°F), its density will decrease as the temperature rises or increase as the temperature falls. The correction factor for the effect of temperature on the density of the water is called *CTL*. A correction factor, *CTDW*, is applied to make a combined correction for the *CTL* associated with the field standard test measures used and the prover under calibration.

CTDW corrects for the effect of the water density change due to a temperature difference between the prover and the test measure. The implementation procedure for *CTDW* is referenced in API MPMS Chapter 12.2 Part 1—Appendix B. API MPMS Chapter 11.2.3 and 11.2.3M can be used to determine *CTDW* values utilized in the water calibration of volumetric provers.

10.1.2 Correction for Compressibility on Water (*CPL*)

The correction factor for the effect of pressure on the water's density (*CPL*) can be calculated using the following expression:

$$CPL = \frac{1}{\{1 - [P - (Pe - Pba)] \times [F]\}}$$

and,

$$(Pe - Pba) \geq 0$$

Where:

Pba = base pressure, in absolute pressure units.
Pe = equilibrium vapor pressure at the temperature of the liquid being measured, in absolute pressure units.
P = operating pressure, in gauge pressure units.
F = compressibility factor for water.

Since water's equilibrium vapor pressure (*Pe*) is considered to be equal to the base pressure (*Pba*), the *CPL* equation for water can be expressed in a simplified form:

$$CPL = \frac{1}{[1 - (P \times F)]}$$

The Compressibility Factor (*F*) for water utilized in the calibration of provers is defined as:

a. For SI Units, a constant (*F*) of value 4.64×10^{-7} per kPa (4.64×10^{-5} per bar).
b. For U.S. Customary Units, a constant (*F*) of value 3.20×10^{-6} per psi.

Open tank provers are calibrated using the waterdraw method at reference (or atmospheric) pressure. As a result, no *CPL* corrections are required for open tank prover calculations.

10.2 PROVER AND TEST MEASURE CORRECTION FACTORS

Prover and test measure correction factors are employed to account for changes in the volumes due to the effects of temperature and pressure upon the steel. These correction factors are:

CTS corrects for thermal expansion and/or contraction of the steel shell due to the average liquid temperature.
CPS corrects for pressure expansion and/or contraction of the steel shell due to the average liquid pressure.

10.2.1 Correction for the Effect of Temperature on Steel (*CTS*)

Any metal container, be it a displacement prover, an open tank prover, or a field standard test measure, when subjected to a change in temperature will change its volume accordingly. The volume change, regardless of prover shape, is proportional to the coefficient of thermal expansion of the material(s). The cubical coefficient of thermal expansion is valid when the calibrated section of the prover and its detector switch mountings are constructed of a single material.

The coefficients of expansion (*Gc*, *Ga*, *Gl*) for the prover, preferably, should be based on data for the materials used in the construction of the calibrated section. However, the values contained in Table 5 shall be used, at the discrimination level shown, if the actual coefficients of expansion are unknown.

The cubical coefficient of expansion (*Gcm*) on the report of calibration reported by the calibrating agency is the one to be used for that individual field standard test measure.

10.2.1.1 *CTS* for Displacement Provers, Open Tank Provers and Field Standard Test Measures

The *CTS* for displacement provers with internal detectors, open tank provers, and field standard test measures assumes a single construction material, and shall be calculated from:

$$CTS = \{1 + [(T - Tb) \times Gc]\}$$

Where:

- Gc = mean coefficient of cubical expansion per degree temperature of the material of which the container is made between Tb and T.
- Tb = base temperature.
- T = average liquid temperature in the container.

The *CTS* equation stated above is applicable to all displacement and tank provers with one exception—small volume provers with externally mounted detectors.

10.2.1.2 *CTS* for Small Volume Provers with External Detectors

For small volume provers which utilize detectors not mounted in the calibrated section of the pipe, the correction factor for the effect of temperature (*CTS*) shall be calculated from:

$$CTS = \{(1 + [(Tp - Tb) \times (Ga)]) \times (1 + [(Td - Tb) \times (Gl)])\}$$

Where:

- Ga = area thermal coefficient of expansion for prover chamber.
- Gl = linear thermal coefficient of expansion on displacer shaft.
- Tb = base temperature.
- Td = temperature of the detector mounting shaft or displacer shaft on *SVP* with external detectors.
- Tp = temperature of the prover chamber.

10.2.2 Correction for the Effect of Pressure on Steel, *CPS*

If a metal container, such as a displacement prover, is subjected to an internal pressure, the walls of the container will stretch elastically and the volume of the container will change accordingly.

The modulus of elasticity (*E*) for a displacement prover, preferably, should be based on data for the materials used in the construction of the calibrated section. However, the values contained in Table 6 shall be used if the modulus of elasticity (*E*) is unknown.

10.2.2.1 Corrections for Single-Walled Container or Prover

While it is recognized that simplifying assumptions enter the equations below, for practical purposes the correction factor for the effect of internal pressure on the volume of a cylindrical container, called *CPS*, may be calculated from:

$$CPS = 1 + \frac{[(Pp - Pbg) \times (ID)]}{(E \times WT)}$$

Since *Pbg*, gauge pressure for water, is equal to zero, the equation simplifies to:

$$CPS = 1 + \frac{(Pp \times ID)}{(E \times WT)}$$

and,

$$ID = [OD - (2 \times WT)]$$

Where:

- Pp = internal operating pressure of prover, in gauge pressure units.
- Pbg = base pressure, in gauge pressure units.
- ID = internal diameter of prover.
- E = modulus of elasticity of the metal in the calibrated section of the prover.
- OD = outside diameter of the prover.
- WT = wall thickness of the prover.

10.2.2.2 Corrections for Double-Walled Container or Prover

For double wall provers, the inner measuring section of the prover is not subjected to a net internal pressure, and the walls of this inner chamber do not stretch elastically. Therefore, in this special case:

$$CPS = 1.000000$$

10.2.2.3 Corrections for Open Tank Prover

For open tank provers, the inner measuring section of the prover is not subjected to a net internal pressure, and the walls of this inner chamber do not stretch elastically. Therefore, in this special case:

$$CPS = 1.000000$$

10.3 COMBINED CORRECTION FACTOR FOR EFFECT OF TEMPERATURE ON STEEL

For the purposes of calculation, the two temperature corrections for thermal expansion of the steel are combined as follows:

$$CCTS = \frac{CTStm}{CTSp}$$

11 Recording of Field Data

11.1 FIELD DATA DISCRIMINATION LEVELS

All required field data shall be recorded and rounded in accordance with the discrimination levels specified in this section. In addition, see section 4.7.2 of this standard.

Field data discrimination levels less than those specified are not permitted in the calculation procedures for determining base prover volumes.

Field data discrimination levels greater than those specified are not in agreement with the intent of this standard and should not be used in the calculation procedures.

The following chart indicates the appropriate table to use for determination of specified discrimination levels for field data.

Prover Data	Table
OD	1
WT	1
ID	1
Tp	2
Pp	3
Fp	4
Gl	5
Ga	5
Gc	5
E	6
SRu	8
SRl	8

Test Measure Data	Table
Ttm	2
Gcm	5
SR	8

Note: For test measures, the thermal expansion coefficients should preferably be obtained from the calibration certificate.

11.2 DISCRIMINATION LEVEL TABLES

Tables 1 through 8 indicate specified discrimination levels and values of constants for calculation data.

Note: In all the tables that follow, the number of "X" to the left of the decimal point is, in most cases, illustrative only and may have a value more or less than the number of "X" shown. The number of digits "X" to the right of the decimal point are however specific and define the discrimination level of each value described.

Table 1—Dimensional Discrimination Levels

	USC (inches)	SI Units (mm)
OD	XX.XXX	XXX.XX
WT	X.XXX	XX.XX
ID	XX.XXX	XXX.XX

Table 2—Temperature Discrimination Levels

	USC (°F)	SI Units (°C)
Prover Temperature (*Tp*)	XX.X	XX.X5
Test Measure Temperature (*Ttm*)	XX.X	XX.X5
Base Temperature (*Tb*)	60.0	15.00

Table 3—Pressure Discrimination Levels

	USC Units		SI Units	
	(psia)	(psig)	(bar)	(kPa)
Base Pressure (*Pb*)	14.696	0.0	1.01325	101.325
Prover Pressure (*Pp*)	XX.X	XX.0	X.XX	XX.0

Table 4—Water Compressibility Factor Discrimination Levels

	USC Units	SI Units	
	(psi)	(bar)	(kPa)
Compressibility Factor (*Fp*)	0.00000320	0.0000464	0.000000464

Table 5—Coefficients of Thermal Expansion for Steel (*Gc, Gcm, Ga, Gl*)*

Type of Steel	Thermal Expansion Coefficient (per °F)	Thermal Expansion Coefficient (per °C)
A. Cubical Coefficient, *Gc, Gcm*		
Mild Carbon	0.0000186	0.0000335
304 Stainless	0.0000288	0.0000518
316 Stainless	0.0000265	0.0000477
17-4 PH Stainless	0.0000180	0.0000324
B. Area Coefficient, *Ga*		
Mild Carbon	0.0000124	0.0000223
304 Stainless	0.0000192	0.0000346
316 Stainless	0.0000177	0.0000318
17-4 PH Stainless	0.0000120	0.0000216
C. Linear Coefficient, *Gl*		
Mild Carbon	0.00000620	0.0000112
304 Stainless	0.00000960	0.0000173
316 Stainless	0.00000883	0.0000159
17-4 PH Stainless	0.00000600	0.0000108

*Other coefficients may be required if prover construction (e.g., detector mountings) use different metals.

Table 6—Modulus of Elasticity Discrimination Levels (*E*)*

Type of Steel	Modulus of Elasticity (per psi)	Modulus of Elasticity (per bar)	Modulus of Elasticity (per kPa)
Mild Carbon	30,000,000	2,068,000	206,800,000
304 Stainless	28,000,000	1,931,000	193,100,000
316 Stainless	28,000,000	1,931,000	193,100,000
17-4 PH Stainless	28,500,000	1,965,000	196,500,000

*Other coefficients may be required if prover construction (e.g., detector mountings) use different metals.

Table 7—Correction Factor Discrimination Levels

CPL	X.XXXXXX
CPS	X.XXXXXX
CTS	X.XXXXXX
CTL	X.XXXXX
CPLp	X.XXXXXX
CPLtm	X.XXXXXX
CTSp	X.XXXXXX
CTStm	X.XXXXXX
CTLp	X.XXXXX
CTLtm	X.XXXXX
CPSp	X.XXXXXX
CPStm	X.XXXXXX
CTDW	X.XXXXXX
CCTS	X.XXXXXX

Table 8—Volume Discrimination Levels

Scale Reading Field Standard Test Measure (*SR*) Open Tank Prover (*SRu, SRl*)	USC Units			SI Units	
	(bbls)	(gals)	(in³)	(l)	(ml)
(*SR*)	—	—	XX.X	—	X.0
(*SRu, SRl*)	X.XXXX	X.XX	—	X.XX	—

Base Prover Volume (*BPV*) Calibrated Prover Volume (*CPV*) Corrected Test Measure Volume (*WD*) Total Corrected Test Measure Volumes (*WDz*) Total Corrected Test Measure Volumes at Base Conditions (*WDzb*)	USC Units (in³)	SI Units (ml)
BPV, CPV, WD, WDz, WDzb	X.XXXX	X.XXX

Targeted (*BPV*) Base prover volume (*BPV*), after user conversion to certificate volume	USC Units		SI Units	
	(bbl)	(gal)	(m³)	(liters)
(*BPV*)	ABC.XXXX	—	—	—
Targeted (*BPV*)	AB.XXXX	ABCD.XX	AB.XXXX	ABCD.XX
	A.XXXXX	ABC.XXX	A.XXXXX	ABC.XXX
	0.XXXXXX	AB.XXXX	0.XXXXXX	AB.XXXX
	—	A.XXXXX	—	—

Field Standard Test Measure Calibrated Volume (*BMV*)
This quantity and its discrimination level shall be taken directly from the test measure calibration certificate.

Test Measure Adjusted Volume (*BMVa*)	USC Units (in³)	SI Units (ml)
BMVa	X.XX	X.X

12 Prover Volume Calculation Sequence and Discrimination Levels

This section rigorously specifies the rounding, calculation sequences and discrimination levels required to determine a base prover volume.

12.1 DISPLACEMENT PROVERS

The following rules for rounding, calculation sequence and discrimination levels are applicable to the volumetric waterdraw calibration of displacement provers (conventional pipe and small volume provers). A flow chart (Figure 1) has been prepared to graphically explain the calculation sequence. Drawings depicting the process have also been prepared to assist the user (see Figures 2, 3, and 4).

When using the waterdraw calibration method on conventional pipe and small volume provers, the recorded pressure shall be the highest pressure experienced by the prover during flow. This pressure reading shall be taken either at the start or the finish of the run when flow is through the solenoid valve.

12.1.1 Field Standard Test Measure Data

Obtain, round, and record the following field standard test measure data relative to all the test measures to be used in the calibration. This information may be obtained from the calibration certificate delivered by the calibrating agency:

a. Base test measure volume (*BMV*).
b. Coefficient of cubical expansion (*Gcm*) of test measure metal of construction.
c. Base temperature (*Tb*).
d. Seal number from the graduated scale of the test measure.
e. Nominal capacity of the test measure.

If the actual value of *Gcm* is known, either as reported on the certificate of calibration or by experimental determination, then it should be used at the same discrimination level as specified in Table 5, otherwise the basic values defined in Table 5 should be used.

Record the value for *BMV*, as indicated on the test measure calibration certificates for all test measures being used.

12.1.2 Prover Data

Obtain, round, and record the following prover data:

a. Prover type and size.
b. Type of steel.
c. Manufacturer.
d. Serial number.
e. Coefficient of thermal expansion (*Gc*) of the prover metal of construction.
f. Modulus of elasticity for prover (*E*).
g. Displacer type and size.
h. Outside diameter of the prover pipe (*OD*).
i. Wall thickness of the prover pipe (*WT*).

Notes:
a. If the type of prover being calibrated is a small volume prover, with external detectors, then *Ga* and *Gl* must also be recorded.
b. If the prover has a double wall construction then $E = 1$.
c. For ball provers record sphere type and circumference or diameter.

Round and record the values for *Gc*, *Ga*, and *Gl* in accordance with Table 5.

Round and record the value of *E* in accordance with Table 6.

Round and record the values for *OD* and *WT* in accordance with Table 1.

Calculate the *ID* of the prover using the following equation:

$$ID = [OD - (2 \times WT)]$$

Round and record the value of the prover *ID* in accordance with Table 1.

12.1.3 Displacement Prover Waterdraw Sequence

Establish water circulation and ensure that the air in the displacement prover has been eliminated by venting at the highest point in the prover. This may require running the displacer several times to ensure the complete elimination of air from the proving system.

When the circulation of water has stabilized both the flowrate and temperature, the calibration can be initiated.

12.1.3.1 Calibration of the Forward "Out" Direction or "Out" Pass Volume

This section is structured to determine the *WDzb* for a single forward "out" pass of the displacement prover.

Step 1 Record Forward "Out" Pass Prover Data—Flowrate, *Tp* and *Pp*

Initiate the waterdraw by "drawing" water into the first certified test measure using a logic circuit in combination with the detector switch.

Obtain and record the flow rate in the prover. Some examples of commonly used methods are: timing the filling of the first test measure, reading a flow meter, or filling all test measures and dividing by the total time. Other acceptable methods may also be used.

Using a certified temperature device (certificate should be available for inspection), record the temperature (*Tp*) of the water *leaving the prover*, once sufficient volume and steady flow rate into the first test measure is established. The prover temperature (*Tp*) should always be taken at the water outlet from the prover, before going into the test measure, under flowing conditions. Record this value as defined in Table 2.

Using a certified pressure device (certificate should be available for inspection) record the pressure of the water in the prover (*Pp*). This pressure can be determined either at the beginning or end of the calibration run, when the water flow is passing through the solenoid valve line into the test measure, and the prover pressure is at its highest value. Read and record this value as defined in Table 3.

All values specified above shall be taken during every "out" calibration pass of the prover.

Step 2 Record Test Measure Data—*SR, Ttm*

After filling the test measure, record the scale reading (*SR*), either above or below the zero line, for every test measure filled, in accordance with Table 8.

Using a certified temperature device, record the temperature of the water in every test measure filled (*Ttm*). Round the value in accordance with Table 2.

The values specified above shall be taken for every test measure filled during a calibration pass.

Step 3 Calculate *BMVa, CTDW, CCTS* and *WD*

Determine *BMVa*

Determine *BMVa* by combining the certified volume of the test measure with the scale reading, for every test measure filled, using the following equation:

$$BMVa = BMV + SR$$

Round the value in accordance with Table 8.

Note: *SR* may be a positive or negative value depending on whether the liquid level is above or below the zero mark. Below zero is negative (*SR*).

Determine *CTDW*

Using API MPMS Chapter 11.2.3 or 11.2.3M, the recorded prover temperature (*Tp*), the test measure temperature (*Ttm*), determine and round the *CTDW* value in accordance with the requirements specified in Table 7.

Determine *CCTS*

Using the coefficient of cubical expansion for the test measure steel (*Gcm*), the recorded temperature of the test measure (*Ttm*), and the base temperature (*Tb*), calculate the *CTStm* factor as follows:

$$CTStm = 1 + (Ttm - Tb) \times Gcm$$

Round the *CTStm* value in accordance with the requirements specified in Table 7.

Using the coefficient of cubical expansion for the prover steel (*Gc*), the recorded prover temperature (*Tp*), and the base temperature (*Tb*), calculate the *CTSp* factor using the following expression for provers with internal detectors:

$$CTSp = 1 + (Tp - Tb) \times Gc$$

Round the *CTSp* value in accordance with the requirements specified in Table 7.

Calculate the *CCTS* value for each fill of the test measure as follows:

$$CCTS = CTStm/CTSp$$

Round the *CCTS* value in accordance with the requirements specified in Table 7.

Determine *WD*

Calculate *WD* using *BMVa, CTDW, CCTS* in the following equation:

$$WD = BMVa \times CTDW \times CCTS$$

Round the *WD* value in accordance with the requirements specified in Table 8.

These are the complete calculation steps necessary to determine the corrected volume of ONE test measure after filling.

Step 4 Forward "Out" Pass Termination

Continue "drawing" water from the prover and filling test measures until activation of the second detector switch, through the logic circuit, signals completion of the "out" calibration pass. Repeat the data collection and calculation sequence in Step 1 through Step 3 for all test measures filled.

Step 5 Calculate *WDz, CPSp, CPLp,* and *WDzb* for the "Out" Pass

Determine *WDz*

When the calibrated section of the prover has been "drawn" completely, determine the total adjusted fill volume for a "pass" (*WDz*) by summing the individual *WD* values for all test measures filled.

$$WDz = @SUM\,(WD)$$

$$WDz = \sum_{1}^{n} (WD)$$

Where:

n = number of test measures filled.

Round the *WDz* value in accordance with the requirements specified in Table 8.

Determine *WDzb*

Using the recorded prover pressure (*Pp*), the internal diameter of the prover (*ID*), the modulus of elasticity for the prover (*E*), and the prover wall thickness (*WT*), calculate *CPSp* using the following expression:

$$CPSp = 1 + [(Pp \times ID)/(E \times WT)]$$

Round the results in accordance with the requirements specified in Table 7.

Using the compressibility factor for water (Fp) specified in Table 4 and the recorded prover pressure (Pp), calculate the $CPLp$ factor using the following expression:

$$CPLp = 1/[1 - (Pp \times Fp)]$$

Round the results in accordance with the requirements specified in Table 7.

Determine the volume of the calibrated section of the prover at base conditions for the "out" pass using the following equation:

$$WDzb(\text{"out"}) = WDz\ /(CPSp \times CPLp)$$

Round the results in accordance with the requirements specified in Table 8.

Step 6 Test for Prover Design

If the prover is unidirectional, proceed to the Run Sequence Termination section (see 12.1.4).

If the prover is bidirectional, proceed to "Back" Pass Sequence to complete the roundtrip.

12.1.3.2 Calibration of the Reverse "Back" Direction or "Back" Pass Volume

The section is structured to determine the $WDzb$ of the calibrated section for a single reverse "back" pass of the displacement prover.

Step 1 Record Reverse "Back" Pass Prover Data—Flowrate, *Tp* and *Pp*

Initiate the waterdraw by "drawing" water into the first certified test measure using a logic circuit in combination with the detector switch.

Obtain and record the flow rate in the prover. Some examples of commonly used methods are: timing the filling of the first test measure, reading a flow meter, or filling all test measures and dividing by the total time. Other acceptable methods may also be used.

Using a certified temperature device (certificate should be available for inspection), record the temperature (Tp) of the water *leaving the prover*, once sufficient volume and steady flow rate into the first test measure is established. The prover temperature (Tp) should always be taken at the water outlet from the prover, before going into the test measure, under flowing conditions. Record this value as defined in Table 2.

Using a certified pressure device (certificate should be available for inspection) record the pressure of the water in the prover (Pp). This pressure can be determined either at the beginning or end of the calibration run, when the water flow is passing through the solenoid valve line into the test measure, and the prover pressure is at its highest value. Read and record this value as defined in Table 3.

All values specified above shall be taken during every "back" calibration pass of the prover.

Step 2 Record Test Measure Data—*SR*, *Ttm*

After filling the test measure, record the scale reading (SR), either above or below the zero line, for every test measure filled in accordance with Table 8.

Using a certified temperature device, record the temperature of the water in every test measure filled (Ttm). Round the value in accordance with Table 2.

The values specified above shall be taken for every test measure filled during a calibration pass.

Step 3 Calculate *BMVa*, *CTDW*, *CCTS* and *WD*

Determine *BMVa*

Determine $BMVa$ by combining the certified volume of the test measure with the scale reading, for every test measure filled, using the following equation:

$$BMVa = BMV + SR$$

Round the value in accordance with Table 8.

Note: SR may be a positive or negative value depending on whether the liquid level is above or below the zero mark. Below zero is negative (SR).

Determine *CTDW*

Using API MPMS Chapter 11.2.3 or 11.2.3M, the recorded prover temperature (Tp), the test measure temperature (Ttm), determine and round the $CTDW$ value in accordance with the requirements specified in Table 7.

Determine *CCTS*

Using the coefficient of cubical expansion for the test measure steel (Gcm), recorded temperature of the test measure (Ttm), and base temperature (Tb), calculate the $CTStm$ factor as follows:

$$CTStm = 1 + (Ttm - Tb) \times Gcm$$

Round the $CTStm$ value in accordance with the requirements specified in Table 7.

Using the coefficient of cubical expansion for the prover steel (Gc), the recorded prover temperature (Tp), and the base temperature (Tb), calculate the $CTSp$ factor using the following expression for provers with internal detectors:

$$CTSp = 1 + (Tp - Tb) \times Gc$$

Round the $CTSp$ value in accordance with the requirements specified in Table 7.

Calculate the *CCTS* value for each fill of the test measure as follows:

$$CCTS = CTStm \,/\, CTSp$$

Round the *CCTS* value in accordance with the requirements specified in Table 7.

Determine *WD*

Calculate *WD* using *BMVa*, *CTDW*, *CCTS* and the following equation:

$$WD = BMVa \times CTDW \times CCTS$$

Round the *WD* value in accordance with the requirements specified in Table 8.

Step 4 Reverse "Back" Pass Termination

Continue "drawing" water from the prover and filling the test measures until activation of the second detector switch, through the logic circuit, signals completion of the "back" calibration pass. Repeat the data collection and calculation sequence in Step 1 through Step 3 for all test measures filled.

Step 5 Calculate *WDz*, *CPSp*, *CPLp*, and *WDzb* for the "Back" Pass

Determine *WDz*

When the calibrated section of the prover has been "drawn" completely, determine the total adjusted fill volume for a "pass" (*WDz*) by summing the individual *WD* values for all test measures filled.

$$WDz = @SUM\,(WD) = \Sigma_1^n\ (WD)$$

Where:

n = number of test measures filled.

Round the results in accordance with the requirements specified in Table 8.

Determine *WDzb*

Using the recorded prover pressure (*Pp*), the internal diameter of the prover (*ID*), the modulus of elasticity for the prover (*E*), and the prover wall thickness (*WT*), calculate *CPSp* using the following expression:

$$CPSp = 1 + [(Pp \times ID) \,/\, (E \times WT)]$$

Round the results in accordance with the requirements specified in Table 7.

Using the compressibility factor for water (*Fp*) specified in Table 4 and the recorded prover pressure (*Pp*), calculate the *CPLp* factor using the following expression:

$$CPLp = 1 \,/\, [1 - (Pp \times Fp)]$$

Round the results in accordance with the requirements specified in Table 7.

Determine the volume of the calibrated section of the prover at base conditions for the "back" pass using the following equation:

$$WDzb(\text{“back”}) = WDz \,/\, (CPSp \times CPLp)$$

Round the results in accordance with the requirements specified in Table 8.

12.1.4 Run Sequence Termination

Uni-directional Prover

If the prover is uni-directional, then the corrected volume as determined from a single calibration run (pass) of the prover is equal to the Calibrated Prover Volume (CPV). This calibration run is equivalent to an "out" pass only calculation, since the "back" pass calculation is not necessary in a uni-directional prover.

$$WDzb(\text{“out”}) = CPV$$

A minimum of three consecutive Calibrated Prover Volumes (CPV) of a uni-directional prover must all be within a range of 0.020 percent to constitute a valid and acceptable calibration.

Calculate the repeatability range as follows:

$$\text{repeatability (\%)} = \frac{(highestCPV - lowestCPV)}{(lowestCPV)} \times 100$$

The Base Prover Volume (BPV) of a uni-directional prover shall be calculated from the average of three or more consecutive Calibrated Prover Volumes (CPV) as shown:

$$BPV = \frac{CPV(1) + CPV(2) + CPV(3)}{3}$$

or:

$$BPV = \frac{\Sigma CPV(n)}{n}$$

Where:

n = number of acceptable consecutive runs.

Round the BPV value in accordance with the requirements specified in Table 8.

Bi-directional Prover

If the prover is bi-directional, then there is a requirement to make calibration passes of the displacer in both forward and reverse direction. The reverse ("back") pass of the displacer is an additional requirement for the purposes of making a complete round-trip. The sum of these two volumes will give the round trip volume for a bi-directional prover.

$$CPV = WDzb(\text{“out”}) + WDzb(\text{“back”})$$

In the case of a bi-directional prover, the following criteria shall be validated for an acceptable calibration:

a. Three or more acceptable consecutive outward passes, *WDzb("out")*, for example, passing the displacer from the left to right direction, must be within a range of 0.020 percent.

b. Three or more acceptable consecutive backward passes, *WDzb("back")*, for example, passing the displacer from the right to left direction, must be within a range of 0.020 percent.

c. Three or more acceptable consecutive round trips, made up of the same passes as described in (a) and (b), which constitute three or more Calibrated Prover Volumes (CPV), must be within a range of 0.020 percent.

$$\%\text{ round trip repeatability (CPV)} = \frac{(highestCPV - lowestCPV)}{(lowestCPV)} \times 100$$

"out" pass repeatability (%)

$$= \frac{(highestWDzb(\text{"out"}) - lowestWDzb(\text{"out"}))}{(lowestWDzb(\text{"out"}))} \times 100$$

"back" pass repeatability (%)

$$= \frac{(highestWDzb(\text{"back"}) - lowestWDzb(\text{"back"}))}{(lowestWDzb(\text{"back"}))} \times 100$$

d. The same flow rate, between the "out" pass and "back" pass, must be maintained for each round trip calibration run.

e. The flow rate criteria for three or more consecutive round trips of the bi-directional prover must have been satisfied.

The Base Prover Volume (BPV) of a bi-directional prover shall be calculated from the average of three or more consecutive Calibrated Prover Volumes (CPV) as shown:

$$BPV = \frac{CPV(1) + CPV(2) + CPV(3)}{3}$$

or:

$$BPV = \frac{\Sigma CPV(n)}{n}$$

Where:

n = number of acceptable consecutive runs.

Round the BPV value in accordance with the requirements specified in Table 8.

If any of the above criteria, for either a uni-directional or bi-directional prover, is not satisfied, then another calibration run sequence must be initiated until all the requirements for an acceptable prover calibration have been met.

Once all of the above criteria have been satisfied, determine the Base Prover Volume (BPV) as the certified volume of the prover, and convert into the required volume units as described in the following section.

12.1.5 Conversion of the BPV into Appropriate Volume Units

After calculation of a Base Prover Volume (BPV), in either cubic inch or cubic centimeter (milliliter) units, it is usually necessary to convert this final prover volume into usable field volumes for meter proving. Conversions shall be done as follows and volumes rounded as specified in Table 8.

a. If the Base Prover Volume (BPV) is determined in cubic inches, then the appropriate conversions are:

BPV (inch^3), divided by 231, equals U.S. gallons @ 60°F.

BPV (inch^3), divided by 9702, equals barrels @ 60°F.

BPV (inch^3), multiplied by 16.387064, divided by 1,000, divided by *CTSp*,[a] equals liters @ 15°C.

BPV (inch^3), multiplied by 16.387064, divided by 1,000,000, divided by *CTSp*,[a] equals cubic meters @ 15°C.

b. If the Base Prover Volume (BPV) is determined in milliliters, then the appropriate conversions are:

BPV (ml), divided by 1,000, equals liters @ 15°C.

BPV (ml), divided by 1,000,000, equals cubic meters @ 15°C.

BPV (ml), divided by 16.387064, divided by 231, multiplied by *CTSp*,[a] equals U.S. gallons @ 60°F.

BPV (ml), divided by 16.387064, divided by 9702, multiplied by *CTSp*,[a] equals barrels @ 60°F.

[a]$CTSp = \{1 + [(60 - 59) \times Gc]\}$, simplified: $CTSp = \{1 + Gc\}$.
Gc = Coefficient of cubical expansion, U.S. Customary Units in °F.

For example (mild steel prover, USC Units):

$$CTSp = 1 + 0.0000186, \quad CTSp = 1.0000186.$$

This *CTSp* factor is used to correct the converted prover volume for the differences in temperatures between the SI and USC conventions (most commonly used to change between 60°F and 15°C). This correction factor, *CTSp*, should be maintained at the same number of decimal places as indicated by the Coefficient of Cubical Expansion (use Table 5), and NOT the number of decimal places shown in Table 7. *This decimal place deviation only applies to this specific application of CTSp.*

For different base temperatures other than 60°F and 15°C, a new *CTSp* will have to be calculated using the new base temperature, e.g. 4°C, 20°C, etc.

All calculations shall be done serially in a continuous chain, in the order shown, to obtain the required converted volumes. Round these final volumes in accordance with Table 8.

Note: For displacement provers with externally mounted detectors, *CTSp* shall be calculated as follows: $CTSp = [1 + (60 - 59)(Ga)]\,[1 + (60 - 59)(Gl)]$; simplified, $CTSp = (1 + Ga)(1 + Gl)$, where Ga and Gl are described in the "Symbols" section and also in Table 5.

(text continued on page 19)

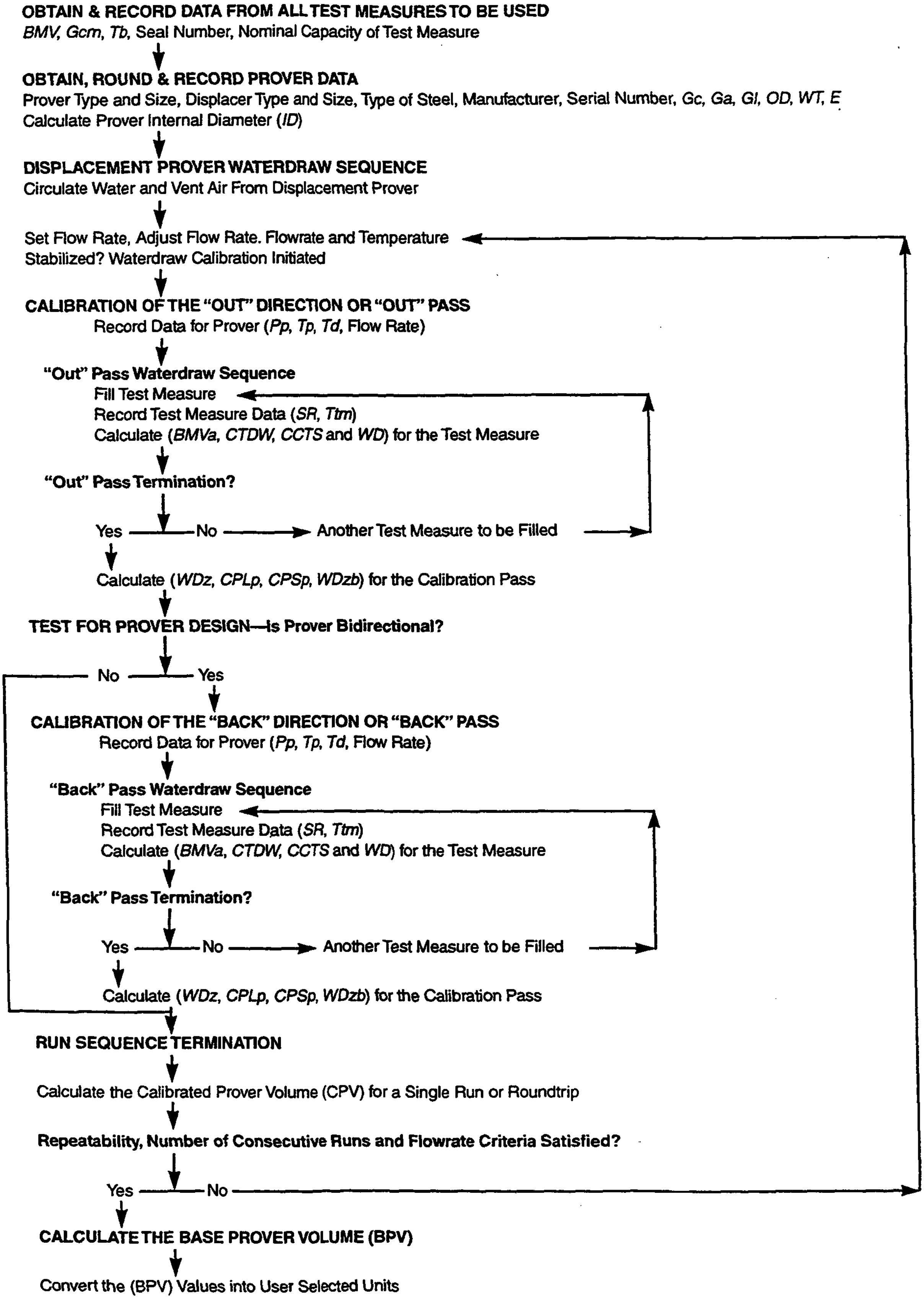

Figure 1—Prover Calibration Flow Chart, Waterdraw Method for Displacement Provers

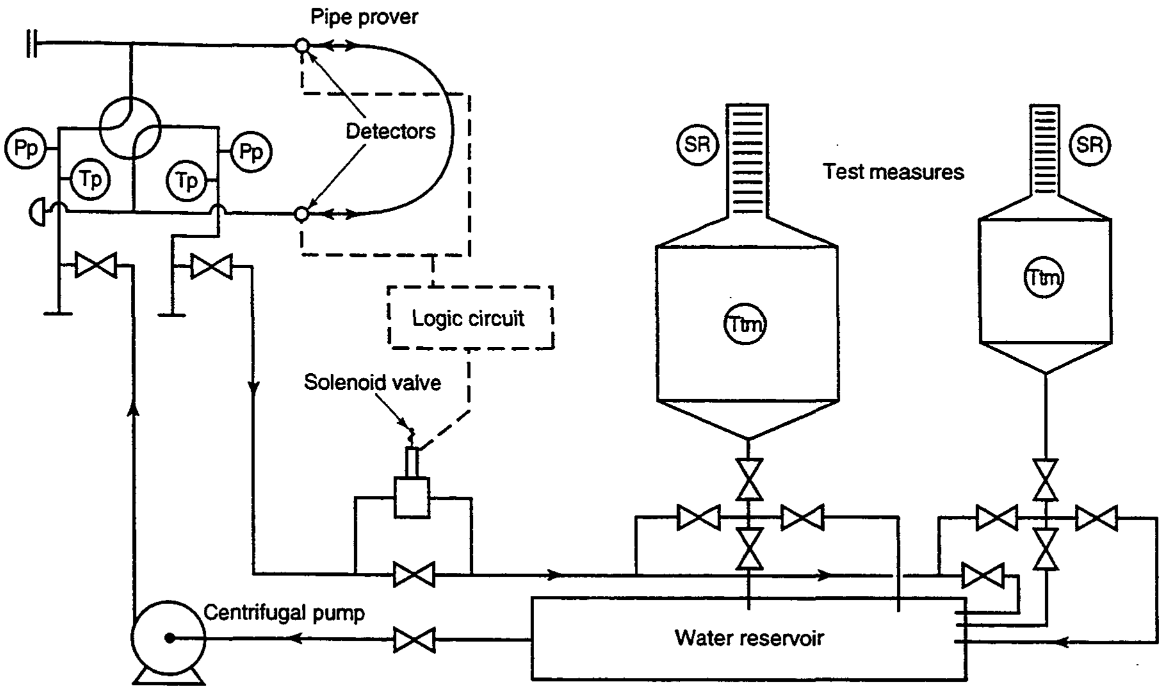

Figure 2—Waterdraw Method of Bidirectional Displacement Provers Using Bottom Filling Test Measures

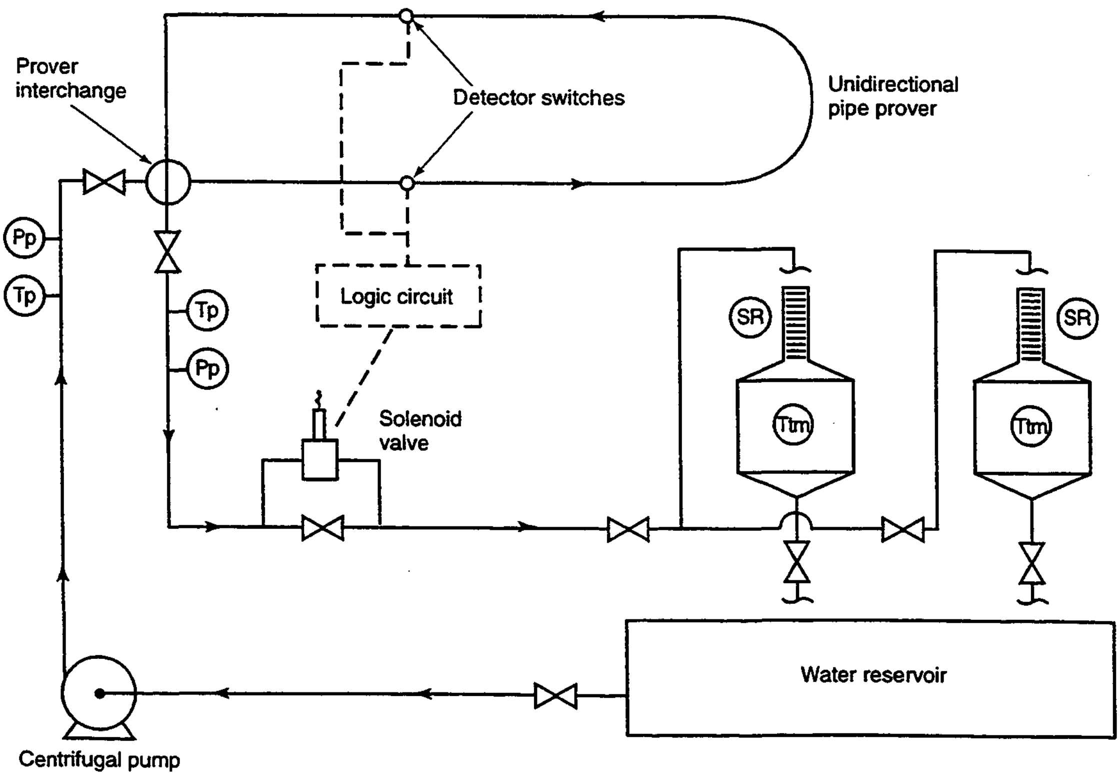

Figure 3—Waterdraw Method of Unidirectional Pipe Prover Using Top Filling Test Measures

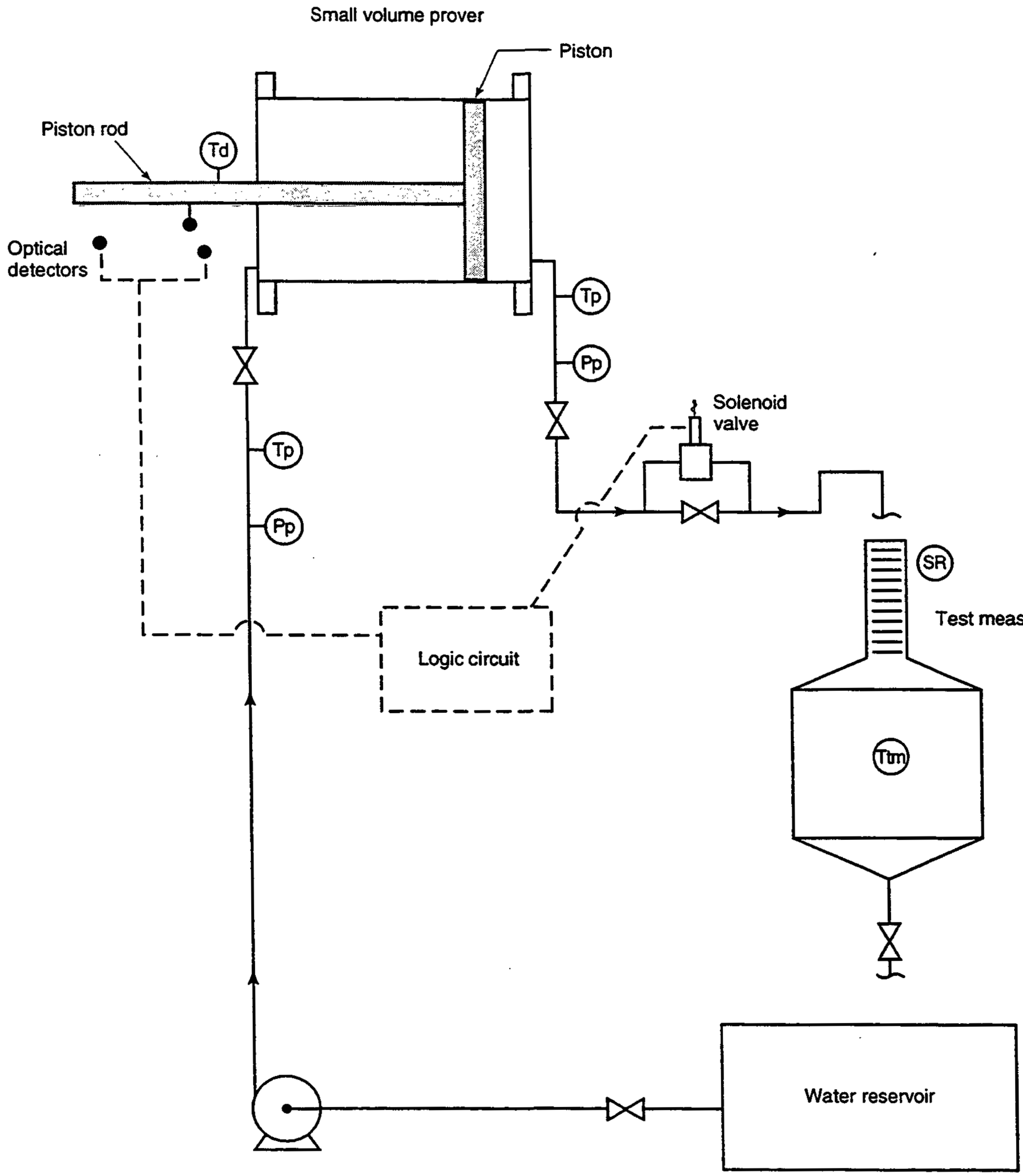

Figure 4—Waterdraw Method of Small Volume Prover Using Top Filling Test Measures

12.2 OPEN TANK PROVERS

The following rules for rounding, calculation sequence and discrimination levels are applicable to the volumetric waterdraw (or waterfill) calibration method for all open tank provers. A flow chart (Figure 5) has been prepared to graphically explain the calculation sequence. Drawings depicting the process have also been prepared to assist the user (Figures 6 and 7).

Tank Prover Neck Scales

For tank provers that have top and bottom necks, either of two methods may be used to calibrate the lower and upper necks of the prover. The first method, commonly used by industry, consists of installing previously marked scales representing a tank table in appropriate units of measurement. The second method consists of determining and marking the actual capacity of the prover on the neck scale.

The Calibrated Prover Volume (CPV) of an open tank prover is the corrected volume from the opening upper scale (*SRu*) reading to the closing lower scale (*SRl*) reading at which withdrawals ceased on any calibration run. Thus, the indicated "to deliver" volume of a prover tank is the difference between the upper scale reading (e.g. 1,000 gallons) and the lower scale reading (e.g. ± zero gallons) after completing the delivery. Ordinarily, the sight glass scale(s) on the prover tank are moved upward/downward at the time of calibration so that the normal volume indicated at standard conditions (upper scale reading minus lower scale reading) is the same as the calibrated volume of the prover tank at standard conditions.

The targeted BPV is a term that refers to adjusting the scales to an even nominal value, such as 500 gallons, or 1,000 gallons. For load rack applications, open tank provers are adjusted to arrive at exactly the targeted BPV value.

The upper scale of a prover tank normally reads the actual accumulated volume at each liquid level (e.g. 999, 1,000, 1,001 gallons, etc.) down to the lower neck scale "zero" position. A field standard test measure reads plus or minus from zero on an upper scale only.

The lower scale of a tank prover usually reads plus or minus zero (in units consistent with the upper scale). However, there are also two other lower scale possibilities:

a. The lower neck does not have a sight glass and the prover tank is simply drained (in the prescribed manner) to essentially empty "zero."

b. The lower neck has a weir type "fixed" zero.

Calibration of neck scales—For new open tank provers, the neck volume should be calibrated, and the neck scale should reflect the linear increments of volume in the neck.

In the calculations it is assumed that the neck scales have previously been calibrated.

The midpoint level of the upper neck scale may be designated the upper reference level.

12.2.1 Field Standard Test Measure Data

Obtain, round, and record the following field standard test measure data relative to all the test measures to be used in the calibration. This information may be obtained from the calibration certificate delivered by the calibrating agency:

a. Base test measure volume (*BMV*).

b. Coefficient of cubical expansion (*Gcm*) of test measure metal of construction.

c. Base temperature (*Tb*).

d. Seal number from the graduated scale of the test measure.

e. Nominal capacity of the test measure.

If the actual value of *Gcm* is known, either as reported on the certificate of calibration or by experimental determination, then it should be used at the same discrimination level as specified in Table 5, otherwise the basic values defined in Table 5 should be used.

Record the value for *BMV*, as indicated on the test measure calibration certificates for all test measures being used.

12.2.2 Tank Prover Data

Obtain, round and record the following data for the open tank prover:

a. Prover type and size.

b. Manufacturer.

c. Serial number.

d. Seal number(s) from the graduated scale(s).

e. Type of steel.

f. Cubical coefficient of thermal expansion (*Gc*).

Record the value for *Gc* in accordance with Table 5.

12.2.3 Open Tank Prover Waterdraw Sequence

Record the targeted *BPV* for the open tank prover in accordance with Table 8.

The open tank prover should be filled with water to read a level on the upper sight glass scale (*SRu*), after which the water is "drawn" from this tank prover into the field standard test measure(s). The calibration should not proceed until the water in the steel shell of the open tank prover, and the water in the field test measures are stabilized at a constant temperature. Drain test measures before starting calibration run.

Initiate the waterdraw sequence by "drawing" water from the prover into the certified test measure(s).

Step 1 Record Opening Tank Prover Data—*SRu, Tp*

Using a certified temperature device (certificate should be available for inspection), determine the average temperature of the water in the prover, *Tp*. Record the value in accordance with Table 2.

Record the upper sight glass gauge scale reading for the tank prover (*SRu*) in accordance with Table 8. The (*SRu*) reading may have either a positive or a negative value.

Step 2 Record Test Measure Data—*SR, Ttm*

Record the scale reading, *SR*, either above or below the zero line, after filling every field standard test measure, in accordance with Table 8.

Using a certified temperature device (certificate should be available for inspection), record the temperature of the water in the test measure (*Ttm*). Round the value in accordance with Table 2.

The values specified above shall be taken for every test measure filled during a calibration run.

Step 3 Calculate *BMVa, CTDW, CCTS,* and *WD*

Determine *BMVa*

Determine *BMVa* by combining the certified volume of the field standard test measure with the scale reading, for every test measure filled, using the following equation:

$$BMVa = BMV + SR$$

Round the value in accordance with Table 8.

Note: *SR* may be a positive or negative value depending on whether the liquid level is above or below the zero mark.

Determine *CTDW*

Using API MPMS Chapter 11.2.3 or 11.2.3M, the recorded prover temperature, *Tp*, and the test measure temperature, *Ttm*, determine the test measure volume adjustment factor, *CTDW*.

Round the *CTDW* value in accordance with Table 7.

Determine *CCTS*

Using the coefficient of cubical expansion for the test measure steel (*Gcm*), the recorded temperature of the test measure (*Ttm*), and the base temperature (*Tb*), calculate the *CTSm* factor:

$$CTSm = 1 + (Ttm - Tb) \times Gcm$$

Round the *CTSm* value in accordance with Table 7.

Using the coefficient of cubical expansion for the prover steel (*Gc*), the recorded prover temperatures (*Tp*), and the base temperature (*Tb*), calculate the *CTSp* factor using the following expression for conventional pipe provers:

$$CTSp = 1 + (Tp - Tb) \times Gc$$

Round the *CTSp* value in accordance with Table 7.

Calculate the *CCTS* value for each fill of the test measure as follows:

$$CCTS = CTSm \,/\, CTSp$$

Round the *CCTS* value in accordance with Table 7.

Determine *WD*

Calculate *WD* using previously determined *BMVa*, *CTDW*, *CCTS* values in the following equation:

$$WD = BMVa \times CTDW \times CCTS$$

Round the *WD* value in accordance with the requirements specified in Table 8.

This completes all the calculation steps necessary to determine the corrected water volume after filling ONE test measure.

Step 4 Open Tank Prover—Water Draw Sequence Termination

The volume of water to be "drawn" from the tank prover may require the filling of several test measures to equal the total volume of water in the open tank prover.

The above calculation Steps 2 and 3 must be repeated for each and every test measure filled during the calibration run.

After filling all test measures required to contain the total open tank prover volume, the draw sequence is terminated.

Step 5 Record Closing Prover Data (*SRl*)

Open tank provers may have top and bottom graduated necks or a top graduated neck only.

For open tank provers with top and bottom neck scales, read the lower sight glass gauge scale (*SRl*) for the prover, and record the value as indicated in Table 8.

For tank provers with a fixed bottom zero scale, adjust the water level to the zero mark and record (*SRl*) = 0.

For tank provers with no bottom scale, drain all the water from the tank prover to empty, and record (*SRl*) = 0.

All types of tank provers should have the same draining times, generally one (1) minute is commonly used.

Step 6 Calculate *WDz* and *WDzb*

Determine *WDz*

After the tank prover has been "drawn" completely, determine the total adjusted fill volume for a calibration run (*WDz*) by summing all individual *WD* values:

$$WDz = @\mathrm{SUM}\,(WD)$$

$$WDz = \sum_{1}^{n} (WD)$$

Where:

n = number of test measures filled.

Round the *WDz* value in accordance with the requirements specified in Table 8.

Determine *WDzb*

To determine the volume of the open tank prover at base conditions (*WDzb*), use the following formula:

$$WDzb = \frac{WDz}{(CPSp \times CPLp)}$$

Since open tank provers are at atmospheric pressure, $Pp = 0$ psig. Therefore:

$$CPSp = 1.000000$$

$$CPLp = 1.000000$$

resulting in,

$$WDzb = WDz$$

Round the *WDzb* value obtained as indicated in accordance with Table 8.

Step 7 Determine the Calibrated Prover Volume (*CPVn*)

The calibrated prover volume for a single run (*CPVn*), of the open tank prover is now calculated from the formula:

$$CPVn = [(WDzb) - (SRu - SRl) + (\text{Targeted } BPV)]$$

(*SRu*) and (*SRl*) are commonly read in gallons, barrels, liters, or cubic meters and must usually be converted to cubic inches or milliliters for calculation purposes.

The units used in the above equation must be consistent. The conversion of units shall be done by multiplying as follows:

a. Barrel times 9,702 equals cubic inches.
b. Gallon times 231 equals cubic inches.
c. Liter times 1,000 equals milliliters.
d. Cubic meter times 1,000,000 equals milliliters.

The values obtained shall be rounded as indicated in Table 8.

Round the Calibrated Prover Volume (CPV) in accordance with the requirements specified in Table 8.

This completes the calculation for one calibration run of the open tank prover to determine the Calibrated Prover Volume (CPV). Additional calibration run(s) shall now be made to obtain at least two (more if required) consecutive Calibrated Prover Volumes (CPV). Therefore, prior to commencing the next calibration run, it will be necessary to refill the tank prover with clean water and allow it to settle before initiating a new calibration run.

12.2.4 Repeatability

The calibration is considered acceptable if the Calibrated Prover Volumes (CPV) of two or more consecutive runs are all within a range of 0.020 percent. The range being defined as:

$$\text{Range (\%)} = \frac{(\text{Highest } CPV - \text{Lowest } CPV)}{(\text{ Lowest } CPV)} \times 100$$

12.2.5 Determine the Base Prover Volume (BPV)

Average the CPV values for the acceptable consecutive runs to determine the Base Prover Volume (BPV) for the open tank prover:

$$BPV = \frac{\sum CPV(n)}{n}$$

Where:

n = number of acceptable consecutive runs.

Round the results in accordance with the requirements specified in Table 8.

12.2.6 Adjustment of Scale(s)

The BPV may not exactly agree with the targeted BPV. Normal practice is then to break the scale seals and adjust one or both of the scales to arrive at exactly the targeted BPV.

For example, if the BPV is 1,000.25 gallons and the targeted BPV is 1,000.00 gallons, the upper scale may be moved downward 0.25 indicated gallons or the lower scale moved upward 0.25 indicated gallons.

Conversely, if the BPV is 999.75 gallons and the targeted BPV is 1,000.00 gallons, the upper scale may be moved upward 0.25 indicated gallons or the lower scale moved downward 0.25 indicated gallons.

On some occasions it may be more practical to move both scales, one upward and one downward, so that each scale shares a part of the overall adjustment.

Reseal the scales after adjustment and record the new numbers.

12.2.7 Verification of New BPV

After adjusting the scale(s), verify that the BPV for the open tank prover agrees with the targeted BPV to within 0.010 percent by performing one or more additional calibration "run(s)."

If this criteria is satisfied, issue a new certificate for the open tank prover. If the above range criteria is not satisfied, continue the waterdraw process.

After verification of the BPV, the scale(s) shall be re-sealed and the seal numbers recorded, the tank prover now has a new Base Prover Volume (BPV).

12.2.8 Conversion of the BPV into Appropriate Volume Units

After verification of the Base Prover Volume (BPV), it is usually necessary to convert this final prover volume from either cubic inch or cubic centimeter (milliliter) units into usable field volumes for meter proving. Conversions shall be done as follows and volumes rounded as specified in Table 8.

a. If the base prover volume is determined in cubic inches, then the appropriate conversions are:

BPV(inch^3), divided by 231, equals U.S. gallons @ 60°F.

BPV(inch^3), divided by 9,702, equals barrels @ 60°F.

BPV(inch^3), multiplied by 16.387064, divided by 1,000, divided by *CTSp*,[a] equals liters @ 15°C.

BPV(inch^3), multiplied by 16.387064, divided by 1,000,000, divided by *CTSp*,[a] equals cubic meters @ 15°C.

b. If the base prover volume is determined in milliliters, then the appropriate conversions are:

BPV(ml), divided by 1,000, equals liters @ 15°C.

BPV(ml), divided by 1,000,000, equals cubic meters @ 15°C.

BPV(ml), divided by 16.387064, divided by 231, multiplied by *CTSp*,[a] equals U.S. gallons @ 60°F.

BPV(ml), divided by 16.387064, divided by 9,702, multiplied by *CTSp*,[a] equals barrels @ 60°F.

[a]$CTSp = \{1 + [(60 - 59) \times Gc]\}$, simplified: $CTSp = \{1 + Gc\}$.
Gc = Coefficient of Cubical Expansion, 1°F.

For example (mild steel prover, USC Units):

$$CTSp = 1 + 0.0000186, \qquad CTSp = 1.0000186$$

This *CTSp* factor is used to correct the converted prover volume for the differences in temperatures between the SI and USC conventions (most commonly used to change between 60°F and 15°C). This correction factor, *CTSp*, should be maintained at the same number of decimal places as indicated by the Coefficient of Cubical Expansion Table (use Table 5), and NOT the number of decimal places shown in Table 7. *This decimal place deviation only applies to this specific application of CTSp.*

For different base temperatures other than 60°F and 15°C, a new *CTSp*, will have to be calculated using the new base temperature, e.g. 4°C, 20°C, etc.

All calculations shall be done serially in a continuous chain, in the order shown, to obtain the required converted volumes. Round these final volumes in accordance with Table 8.

OBTAIN & RECORD DATA FROM ALL TEST MEASURES TO BE USED
BMV, Gcm, Tb, Seal Number, Nominal Capacity of Test Measure

OBTAIN, ROUND & RECORD PROVER DATA
Gc, Prover Type and Size, Displacer Type and Size, Type of Steel, Manufacturer, Serial Number.

OPEN TANK PROVER WATERDRAW SEQUENCE
Round and Record the Targeted CPV for the Open Tank

(The open tank prover should be filled with water to read a level on the upper sight glass scale (*SRu*), after which the water is "drawn" from this tank prover into the field standard test measure(s). The calibration should not proceed until the Open Tank Prover's steel shell, the water in the prover, and the field test measures are stabilized at approximately the same temperature.)

Record Opening Tank Prover Data (*SRu, Tp*)

DRAW WATER FROM TANK PROVER INTO TEST MEASURE(S)
"Draw" Water From the Prover Into Certified Test Measure(s)

Record Test Measure Data (*SR, Ttm*)
Calculate Test Measures' *BMVa, CTDW,* and *CCTS*
Calculate Test Measure *WD*

Draw Sequence Termination?

Yes — No → Another Test Measure to be Filled

Record Closing Open Tank Prover Data (*SRl*)
Calculate *WDz* and *WDzb* for the Waterdraw Run

RUN SEQUENCE TERMINATION

Calculate the Calibrated Prover Volume (CPV) for a Single Run

Repeatability, and Number of Consecutive Runs Criteria Satisfied?

Yes — No

Determine the Base Prover Volume (BPV)

ADJUSTMENT OF SCALE(S)
Adjust the Scale(s) so That the Tank Prover BPV Equals the Targeted BPV

VERIFICATION OF NEW BPV
After Adjusting the Scale(s), Verify the Following:

Is the BPV Reproducible to Within 0.010 Percent or Less?

Yes — No

Seal the Scales and Record the Seal Numbers.

CALCULATE THE BASE PROVER VOLUME

Convert the BPV Values Into User Selected Units

Figure 5—Prover Calibration Flow Chart—Waterdraw Method for Open Tank Provers

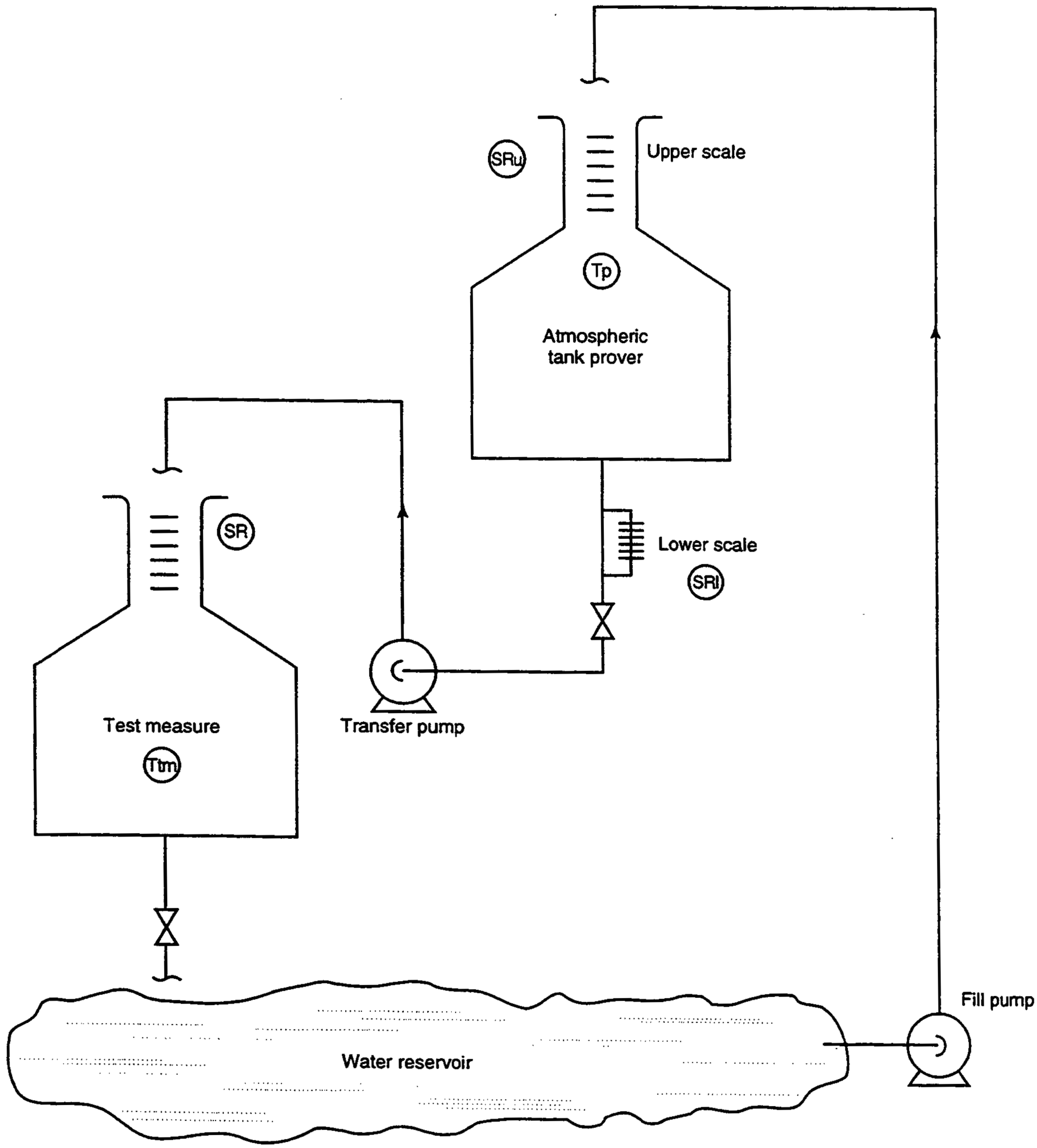

Figure 6—Waterdraw Method of Open Tank Provers Using Top Filling Test Measures

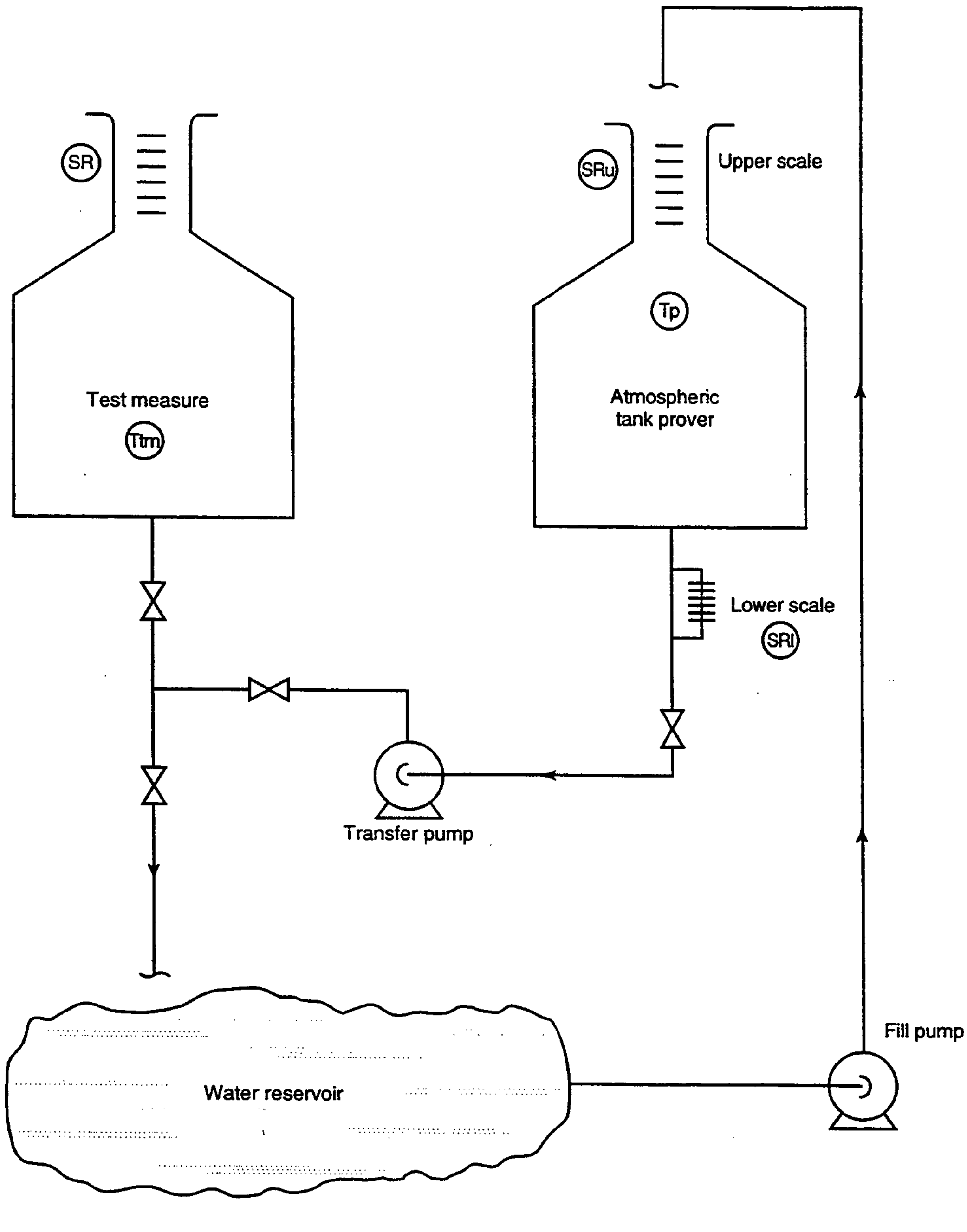

Figure 7—Waterdraw Method of Open Tank Provers Using Bottom Filling Test Measures

13 Base Prover Volume Calculation Examples

13.1 DISPLACEMENT PROVER—CONVENTIONAL UNIDIRECTIONAL PIPE DESIGN

The following example depicts the calculations and required documentation for a complete unidirectional prover waterdraw calibration.

EXAMPLE NO. 1
WATERDRAW CALIBRATION
DISPLACEMENT PROVER—UNIDIRECTIONAL TYPE

(A) GENERAL PROVER INFORMATION

Waterdraw calibration date			______
Waterdraw calibration report number			______
Owner of meter prover			______
Location of meter prover			______
Manufacturer of meter prover			______
Serial number of meter prover			______
Type of meter prover			Conventional pipe prover—unidirectional—single wall
Prover volume identification			Single set of detectors
Type of steel in meter prover			Mild Carbon Steel
OD	=	Outside Diameter of measuring chamber	6.625 inches
ID	=	Inside Diameter of measuring chamber	5.761 inches
WT	=	Wall Thickness of measuring chamber	0.432 inches
E	=	Modulus of Elasticity	30,000,000 per psig
Gc	=	Coefficient of cubical expansion	0.0000186 per degree F
Tb	=	Base Temperature for the prover	60 degrees F

(B) FIELD STANDARD TEST MEASURES

REF	=	Reference measure number	Ref 1	Ref 2	Ref 3
SEAL	=	NIST seal number on measure	ffff	hhhh	nnnn
NOM	=	Nominal volume in U.S. Gallons	50	30	5
BMV	=	Base Measure Volume (cubic inches)	11551.50	6931.27	1155.23
Gcm	=	Coeff. cubical expansion per degree F	0.0000265	0.0000265	0.0000265
Tb	=	Base Temperature for the measure	60 degrees F	60 degrees F	60 degrees F

(C) CALIBRATION PASS DATA

Calibration Pass/Run Numbers			Pass 1 = Run I, Pass 2 = Run II and Pass 3 = Run III		
Time at start of each calibration pass			Time		
Weather during each calibration pass			Weather		
Flow rate at filling of field standard measure			Run I @ 50 GPM, Run II @ 25 GPM and Run III @ 50 GPM		
Tp	=	Starting prover temperature on downstream side of prover on each pass			
Pp	=	Starting prover pressure while approaching first detector on each pass			
FILL	=	Measure fill number	w/each fill	Fill Numbers:	1, 2, 3 and 4 for each pass
REF	=	Measure reference number	w/each fill	Ref Numbers:	2, 3, 1 and 3 for each pass
BMV	=	Base Measure Volume	w/each fill	Cubic Inches:	6931.27, 1155.23, 11551.50, 1155.23
SR	=	Scale reading on test measure	w/each fill	Plus or minus scale readings in cubic inches	
BMVa	=	Adjusted Volumes	w/each fill	BMVa = (*BMV* + *SR*)	
Ttm	=	Temperature Test Measure	w/each fill	Temperature in Measure for each fill	

(D) CALCULATIONS FOR CALIBRATION PASS

CTDW	=	Table in Chapter 11.2.3	w/each fill	on any given pass	
CTSp	=	1+(*Tp*–*Tb*)*(*Gc*)	w/each fill	on any given pass	
CTStm	=	1+(*Ttm*–*Tb*)*(*Gcm*)	w/each fill	on any given pass	
CCTS	=	(*CTSm* / *CTSp*)	w/each fill	on any given pass	
WD	=	(*BMVa***CTDW***CCTS*)	w/each fill	on any given pass	
WD1	=	(*BMVa***CTDW***CCTS*)	w/ Fill No. 1	on any given pass	*WD1*
WD2	=	(*BMVa***CTDW***CCTS*)	w/ Fill No. 2	on any given pass	*WD2*
WDn	=	(*BMVa***CTDW***CCTS*)	w/ Fill No. n	on any given pass	*WDn*
WDz	=	*WD1* + *WD2* + ... + *WDn*	(sum of *WD*s from Fill Nos. 1, 2, ..., *n*) on each pass		*WDz*
CPSp	=	1 + (*Pp* * *ID*)/(*E* * *WT*)	for each pass		*CPSp*
CPLp	=	1 / [1–(0.0000032 * *Pp*)]	for each pass		*CPLp*
WDzb	=	*WDz* / (*CPSp* * *CPLp*)	(total cubic inches at *Tb* and *Pb*) on each pass		*WDzb*

Example No. 1—Prover and Measure Information
Waterdraw Calibration—Displacement Prover—Unidirectional Type

Date: ______________________ Report No. ______________________

Owner: ______________________ Operator: ______________________

Calibration Site: ______________________ Service Location: ______________________

Weather: ______________________ Sheet No. 1 of: ______________________

Prover Manufacturer: ______________________

Volume Identification: ______________________ Type of Prover: Unidirectional Pipe w/ 1-Wall

Serial Number: ______________________ Material: Mild Carbon Steel

Cubical Coefficient of Expansion / Degree F:		*Gc*	=	0.0000186
Square Coefficient of Expansion / Degree F:		*Ga*	=	0.0000124
Linear Coefficient of Expansion / Degree F:		*Gl*	=	0.0000062
Modulus of Elasticity per psi		*E*	=	30000000
Outside Diameter of Prover	(inches)	*OD*	=	6.625
Wall Thickness of Prover	(inches)	*WT*	=	0.432
Inside Diameter of Prover	(inches)	*ID*	=	5.761

Field Standard Test Measures:

FILL	=	Number used to designate the order of recording the fills
REF	=	Reference number used to designate the measure being used
SEAL	=	Seal number installed by the Calibration Agency (e.g. NIST)
BMV	=	Base Measure Volume of field standard test measure @ 60 deg F
Gcm	=	Cubical coefficient of thermal expansion per degree F

REF No.	BMV cu. in.	Nominal gallons	SEAL No.	*Gcm*
1	11551.50	50	ffff	0.0000265
2	6931.27	30	hhhh	0.0000265
3	1155.23	5	nnnn	0.0000265

Calib. Tech: ______________________ Company: ______________________

Witnessed by: ______________________ Company: ______________________

Witnessed by: ______________________ Company: ______________________

Example No. 1—Pass No. 1—w/ Computer
Waterdraw Calibration—Displacement Prover—Unidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
1	1	Unidirectional	50 GPM	86.0	n/a	*Pp* = 39 psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	6931.27	–4.0	6927.27	86.4	0.999932	1.000216	6928.2951
2	3	1155.23	0.0	1155.23	86.5	0.999915	1.000218	1155.3836
3	1	11551.50	69.0	11620.50	86.4	0.999932	1.000216	11622.2197
4	3	1155.23	11.5	1166.73	86.5	0.999915	1.000218	1166.8852
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM WD @ 60 DEGREES F	20872.7836
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000017
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000125
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	20869.8200

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 1—Pass No. 2—w/ Computer
Waterdraw Calibration—Displacement Prover—Unidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
2	1	Unidirectional	25 GPM	86.5	n/a	*Pp* = 39 psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	6931.27	–5.0	6926.27	87.0	0.999915	1.000223	6927.2257
2	3	1155.23	–0.5	1154.73	87.0	0.999915	1.000223	1154.8893
3	1	11551.50	70.0	11621.50	87.0	0.999915	1.000223	11623.1035
4	3	1155.23	12.5	1167.73	87.0	0.999915	1.000223	1167.8911
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM WD @ 60 DEGREES F	20873.1096
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000017
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000125
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	20870.1460

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 1—Pass No. 3—w/ Computer
Waterdraw Calibration—Displacement Prover—Unidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
3	1	Unidirectional	50 GPM	87.5	n/a	*Pp* = 39 psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	6931.27	–6.0	6925.27	87.7	0.999965	1.000222	6926.5650
2	3	1155.23	0.0	1155.23	87.8	0.999948	1.000225	1155.4298
3	1	11551.50	72.0	11623.50	87.9	0.999931	1.000227	11625.3363
4	3	1155.23	11.0	1166.23	87.9	0.999931	1.000227	1166.4142
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM WD @ 60 DEGREES F	20873.7453
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000017
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000125
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	20870.7816

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 1—Summary—w/ Computer
Waterdraw Calibration—Displacement Prover—Unidirectional Type

Date: ____________________ Time: ______________ Report Number: ______________________________

Sheet No: ________________ Of: ________________ Manufacturer: ______________________________

Weather: ____ Serial Number: ______________________________

Owner/Operator: __________________________________ Location: ______________________________

PROVER CALIBRATION SUMMARY

Pass/Run No. I	=	20869.8200	@	50 GPM
Pass/Run No. II	=	20870.1460	@	25 GPM
Pass/Run No. III	=	20870.7816	@	50 GPM

Calculated Range Percent = 0.005%

Calculated Range Percent = [(MAX – MIN)/(MIN)] * [100]

Allowable Range Percent = 0.020 %

Note: Above summary in cubic inches @ 60 degrees F & 0 psig.
Note: Data obtained & calculations performed in U.S. Customary Units.

Solve for BASE PROVER VOLUME: AVERAGE Pass/Runs I, II and III

Cubic Inches	(16.387064 Cubic Centimeters)	@ 60°F & 0 PSIG	=	20870.2492
U.S. Gallons	(231 Cubic Inches)	@ 60°F & 0 PSIG	=	90.3474
Barrels	(9702 Cubic Inches)	@ 60°F & 0 PSIG	=	2.15113
Cubic Feet	(1728 Cubic Inches)	@ 60°F & 0 PSIG	=	12.0777
Liters	(1000 Cubic Meters)	@ 15°C & 101.325 kPa	=	341.996
Cubic Meters	(1000 Liters)	@ 15°C & 101.325 kPa	=	0.341996

Diameter of Displacer in Inches ____________ = ____________ % *ID* of Pipe

Calibrator's Name & Company Name ______________________________________

13.2 DISPLACEMENT PROVER—CONVENTIONAL BIDIRECTIONAL PIPE DESIGN

The following example depicts the calculations and required documentation for a conventional bidirectional prover waterdraw calibration.

EXAMPLE NO. 2
WATERDRAW CALIBRATION
DISPLACEMENT PROVER—BIDIRECTIONAL TYPE

(A) GENERAL PROVER INFORMATION

Waterdraw calibration date			
Waterdraw calibration report number			
Owner of meter prover			
Location of meter prover			
Manufacturer of meter prover			
Serial number of meter prover			
Type of meter prover		Conventional pipe prover—bidirectional—single wall	
Prover volume identification		Single set of detectors	
Type of steel in meter prover			316 Stainless Steel
OD	=	Outside Diameter of measuring chamber	10.750 inches
ID	=	Inside Diameter of measuring chamber	10.020 inches
WT	=	Wall Thickness of measuring chamber	0.365 inches
E	=	Modulus of Elasticity	28,000,000 per psig
Gc	=	Coefficient of cubical expansion	0.0000265 per degree F
Tb	=	Base Temperature for the prover	60 degrees F

(B) FIELD STANDARD TEST MEASURES

REF	=	Reference measure number	Ref 1	Ref 2
SEAL	=	NIST seal number on measure	gggg	jjjj
NOM	=	Nominal volume in U.S. Gallons	50	21
BMV	=	Base Measure Volume (cubic inches)	11547.80	4845.87
Gcm	=	Coeff. cubical expansion per degree F	0.0000265	0.0000265
Tb	=	Base Temperature for the measure	60 degrees F	60 degrees F

(C) CALIBRATION PASS DATA

Calibration Pass/Run Numbers	Passes 1 & 2 = Run I, Passes 3 & 4 = Run II and Passes 5 & 6 = Run III
Time at start of each calibration pass	Time
Weather during each calibration pass	Weather
Flow rate at filling of field standard measure	Run I @ 40 GPM, Run II @ 20 GPM and Run III @ 60 GPM

Tp	=	Starting prover temperature on downstream side of prover for each pass.			
Pp	=	Starting prover pressure while approaching first detector on each pass.			
FILL	=	Measure fill number	w/each fill	Fill Numbers:	1, 2 and 3 for each pass
REF	=	Measure reference number	w/each fill	Ref Numbers:	2, 1 and 2 for each pass
BMV	=	Base Measure Volume	w/each fill	Cubic Inches:	4845.87, 11547.80 and 4845.87
SR	=	Scale reading on test measure	w/each fill	Plus or minus scale readings in cubic inches	
BMVa	=	Adjusted Volumes	w/each fill	$BMVa = (BMV + SR)$	
Ttm	=	Temperature Test Measure	w/each fill	Temperature in measure for each fill	

(D) CALCULATIONS FOR CALIBRATION PASS

CTDW	=	Table in Chapter 11.2.3	w/each fill	on any given pass
CTSp	=	$1+(Tp-Tb)*(Gc)$	w/each fill	on any given pass
CTStm	=	$1+(Ttm-Tb)*(Gcm)$	w/each fill	on any given pass
CCTS	=	$(CTSm / CTSp)$	w/each fill	on any given pass
WD	=	$(BMVa*CTDW*CCTS)$	w/each fill	on any given pass

WD1	=	$(BMVa*CTDW*CCTS)$	w/ Fill No. 1	on any given pass	*WD1*
WD2	=	$(BMVa*CTDW*CCTS)$	w/ Fill No. 2	on any given pass	*WD2*
WDn	=	$(BMVa*CTDW*CCTS)$	w/ Fill No. n	on any given pass	*WDn*
WDz	=	$WD1 + WD2 + ... + WDn$	(sum of *WD*s from Fill Nos. 1, 2, ..., *n*) on each pass		*WDz*
CPSp	=	$1 + (Pp * ID)/(E * WT)$	for each pass		*CPSp*
CPLp	=	$1 / [1-(0.0000032 * Pp)]$	for each pass		*CPLp*
WDzb	=	$WDz / (CPSp * CPLp)$	(total cubic inches at *Tb* and *Pb*) on each pass		*WDzb*

Example No. 2—Prover and Measure Information
Waterdraw Calibration—Displacement Prover—Bidirectional Type

Date: ____________________ Report No. ____________________

Owner: ____________________ Operator: ____________________

Calibration Site: ____________________ Service Location: ____________________

Weather: ____________________ Sheet No. 1 of: ____________________

Prover Manufacturer: ____________________

Volume Identification: ____________________ Type of Prover: Bidirectional Pipe w/ 1-Wall

Serial Number: ____________________ Material: 316 Stainless Steel

Cubical Coefficient of Expansion / Degree F:		*Gc*	=	0.0000265
Square Coefficient of Expansion / Degree F:		*Ga*	=	0.0000177
Linear Coefficient of Expansion / Degree F:		*Gl*	=	0.0000088
Modulus of Elasticity per psi		*E*	=	28000000
Outside Diameter of Prover	(inches)	*OD*	=	10.750
Wall Thickness of Prover	(inches)	*WT*	=	0.365
Inside Diameter of Prover	(inches)	*ID*	=	10.020

Field Standard Test Measures:

FILL	=	Number used to designate the order of recording the fills
REF	=	Reference number used to designate the measure being used
SEAL	=	Seal number installed by the calibration agency (e.g. NIST)
BMV	=	Base Measure Volume of field standard test measure @ 60 deg F
Gcm	=	Cubical coefficient of thermal expansion per degree F

REF No.	*BMV* cu. in.	Nominal gallons	SEAL No.	*Gcm*
1	11547.80	50	gggg	0.0000265
2	4845.87	21	jjjj	0.0000265

Calib. Tech: ____________________ Company: ____________________

Witnessed by: ____________________ Company: ____________________

Witnessed by: ____________________ Company: ____________________

Example No. 2—Pass No. 1—w/ Computer
Waterdraw Calibration—Displacement Prover—Bidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
1	1	"Out"	40 GPM	55.8	n/a	$Pp = 40$ psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	4845.87	2.0	4847.87	55.6	1.000014	0.999994	4847.9088
2	1	11547.80	–48.0	11499.80	55.6	1.000014	0.999994	11499.8920
3	2	4845.87	–10.5	4835.37	55.6	1.000014	0.999994	4835.4087
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM *WD* @ 60 DEGREES F	21183.2095
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000039
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000128
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	21179.6724

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 2—Pass No. 2—w/ Computer
Waterdraw Calibration—Displacement Prover—Bidirectional Type

Date: ____________________ Time: ______________ Report Number: ______________________________

Sheet No: ________________ Of: ________________ Manufacturer: ______________________________

Weather: ______________________________________ Serial Number: ______________________________

Owner/Operator: _______________________________ Location: ___________________________________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
2	1	"Back"	40 GPM	56.1	n/a	$Pp = 40$ psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	4845.87	2.0	4847.87	55.8	1.000022	0.999992	4847.9379
2	1	11547.80	–11.0	11536.80	55.9	1.000015	0.999994	11536.9038
3	2	4845.87	–20.0	4825.87	55.6	1.000036	0.999986	4825.9762
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM *WD* @ 60 DEGREES F	21210.8179
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000039
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000128
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	21207.2762

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ______________________ Company: ______________________________

Witnessed by: _________________________ Company: ______________________________

Witnessed by: _________________________ Company: ______________________________

Example No. 2—Pass No. 3—w/ Computer
Waterdraw Calibration—Displacement Prover—Bidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
3	1	"Out"	20 GPM	56.2	n/a	$Pp = 40$ psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	4845.87	2.0	4847.87	56.2	1.000000	1.000000	4847.8700
2	1	11547.80	–46.0	11501.80	56.2	1.000000	1.000000	11501.8000
3	2	4845.87	–10.0	4835.87	55.6	1.000043	0.999984	4836.0006
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM *WD* @ 60 DEGREES F	21185.6706
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000039
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000128
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	21182.1331

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 2—Pass No. 4—w/ Computer
Waterdraw Calibration—Displacement Prover—Bidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
4	1	"Back"	20 GPM	56.2	n/a	*Pp* = 40 psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	4845.87	1.0	4846.87	56.2	1.000000	1.000000	4846.8700
2	1	11547.80	–19.0	11528.80	56.2	1.000000	1.000000	11528.8000
3	2	4845.87	–9.5	4836.37	55.6	1.000043	0.999984	4836.5006
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM *WD* @ 60 DEGREES F	21212.1706
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000039
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000128
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	21208.6287

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 2—Pass No. 5—w/ Computer
Waterdraw Calibration—Displacement Prover—Bidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
5	1	"Out"	60 GPM	56.4	n/a	$Pp = 40$ psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	4845.87	3.5	4849.37	56.2	1.000015	0.999994	4849.4136
2	1	11547.80	–50.0	11497.80	56.5	0.999993	1.000002	11497.7425
3	2	4845.87	–7.5	4838.37	55.6	1.000058	0.999978	4838.5442
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM *WD* @ 60 DEGREES F	21185.7003
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000039
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000128
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	21182.1628

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 2—Pass No. 6—w/ Computer
Waterdraw Calibration—Displacement Prover—Bidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
6	1	"Back"	60 GPM	56.5	n/a	*Pp* = 40 psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	4845.87	–8.0	4837.87	56.3	1.000015	0.999995	4837.9184
2	1	11547.80	–19.0	11528.80	56.6	0.999993	1.000003	11528.7539
3	2	4845.87	–1.5	4844.37	55.6	1.000066	0.999976	4844.5735
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM *WD* @ 60 DEGREES F	21211.2458
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000039
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000128
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	21207.7040

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 2—Summary—w/ Computer
Waterdraw Calibration—Displacement Prover—Bidirectional Type

Date: ____________________ Time: ______________ Report Number: ____________________________

Sheet No: ________________ Of: ________________ Manufacturer: ____________________________

Weather: ______________________________________ Serial Number: ___________________________

Owner/Operator: _______________________________ Location: ________________________________

PROVER CALIBRATION SUMMARY

		Out Passes	Back Passes	Round Trips I, II, III	
Pass No. 1	=	21179.6724			
Pass No. 2	=		21207.2762	42386.9486	@ 40 GPM
Pass No. 3	=	21182.1331			
Pass No. 4	=		21208.6287	42390.7618	@ 20 GPM
Pass No. 5	=	21182.1628			
Pass No. 6	=		21207.7040	42389.8668	@ 60 GPM
Calculated Ranges:					
		0.012 %	0.006 %	0.009 %	

Calculated Ranges = [(MAX – MIN)/(MIN)] * [100]

Allowable Range = 0.020 %

Note: Above summary in cubic inches @ 60 degrees F & 0 psig.
Note: Data obtained & calculations performed in U.S. Customary Units.

Solve for BASE PROVER VOLUME: AVERAGE Round Trips I, II and III

Cubic Inches	(16.387064 Cubic Centimeters)	@ 60°F & 0 PSIG	=	42389.1924
U.S. Gallons	(231 Cubic Inches)	@ 60°F & 0 PSIG	=	183.503
Barrels	(9702 Cubic Inches)	@ 60°F & 0 PSIG	=	4.36912
Cubic Feet	(1728 Cubic Inches)	@ 60°F & 0 PSIG	=	24.5308
Liters	(1000 Cubic Meters)	@ 15°C & 101.325 kPa	=	694.616
Cubic Meters	(1000 Liters)	@ 15°C & 101.325 kPa	=	0.694616

Diameter of Displacer in Inches ___________ = ___________ % *ID* of Pipe

Calibrator's Name & Company Name ______________________________________

13.3 DISPLACEMENT PROVER—UNIDIRECTIONAL SMALL VOLUME PROVER DESIGN

The following example depicts the calculations and required documentation for a unidirectional small volume prover waterdraw calibration.

EXAMPLE NO. 3
WATERDRAW CALIBRATION
SMALL VOLUME DISPLACEMENT PROVER W/ EXTERNAL DETECTORS—UNIDIRECTIONAL TYPE

(A) GENERAL PROVER INFORMATION

Waterdraw calibration date			______
Waterdraw calibration report number			______
Owner of meter prover			______
Location of meter prover			______
Manufacturer of meter prover			______
Serial number of meter prover			______
Type of meter prover			Small volume prover—external detectors—single wall
Prover volume identification			Downstream Volume
Type of steel in meter prover			17-4 PH Stainless Steel
Type of steel on detector mounting shaft			Special alloy
OD	=	Outside Diameter of measuring chamber	14.000 inches
ID	=	Inside Diameter of measuring chamber	12.250 inches
WT	=	Wall Thickness of measuring chamber	0.875 inches
E	=	Modulus of Elasticity	28,500,000 per psig
Ga	=	Coefficient of square (area) expansion	0.0000120 per degree F
Gl	=	Coefficient of linear expansion	0.0000008 per degree F
Tb	=	Base Temperature for the prover	60 degrees F

(B) FIELD STANDARD TEST MEASURES

REF	=	Reference measure number	Ref 1
SEAL	=	NIST seal number on measure	kkkk
NOM	=	Nominal volume in U.S. Gallons	15
BMV	=	Base Measure Volume (cubic inches)	3463.22
Gcm	=	Coefficient of cubical expansion	0.0000265 per degree F
Tb	=	Base Temperature for the measure	60 degrees F

(C) CALIBRATION PASS DATA

Calibration Pass/Run Numbers	Pass 1 = Run I, Pass 2 = Run II and Pass 3 = Run III
Time at start of each calibration pass	Time
Weather during each calibration pass	Weather
Flow rate at filling of field standard measure	Run I @ 20 GPM, Run II @ 10 GPM and Run III @ 20 GPM

Tp	=	Starting prover temperature on downstream side of prover for each pass			
Td	=	Temperature on detector mounting shaft for each pass			
Pp	=	Starting prover pressure while approaching first detector on each pass			
FILL	=	Measure fill number	w/each fill	Fill Number:	1 for each pass
REF	=	Measure reference number	w/each fill	Ref Number:	1 for each pass
BMV	=	Base Measure Volume	w/each fill	Cubic Inches:	3463.22
SR	=	Scale reading on test measure	w/each fill	Plus or minus scale readings in cubic inches	
BMVa	=	Adjusted Volumes	w/each fill	$BMVa = (BMV + SR)$	
Ttm	=	Temperature Test Measure	w/each fill	Temperature in measure for each fill	

(D) CALCULATIONS FOR CALIBRATION PASS

CTDW	=	Table in Chapter 11.2.3	w/each fill	on any given pass
CTSp	=	$[1+(Tp-Tb)*(Ga)] * [1+(Td-Tb)*(Gl)]$	w/each fill	on any given pass
CTStm	=	$1+(Ttm-Tb)*(Gcm)$	w/each fill	on any given pass
CCTS	=	$(CTSm / CTSp)$	w/each fill	on any given pass
WD	=	$(BMVa*CTDW*CCTS)$	w/each fill	on any given pass

WD1	=	$(BMVa*CTDW*CCTS)$	w/ Fill No. 1 on any given pass	*WD1*
WD2	=	$(BMVa*CTDW*CCTS)$	w/ Fill No. 2 on any given pass	*WD2*
WDn	=	$(BMVa*CTDW*CCTS)$	w/ Fill No. n on any given pass	*WDn*
WDz	=	$WD1 + WD2 + ... + WDn$	(sum of *WD*s from Fill Nos. 1, 2, ..., *n*) on each pass	*WDz*
CPSp	=	$1 + (Pp * ID)/(E * WT)$	for each pass	*CPSp*
CPLp	=	$1 / [1-(0.0000032 * Pp)]$	for each pass	*CPLp*
WDzb	=	$WDz / (CPSp * CPLp)$	(total cubic inches at *Tb* and *Pb*) on each pass	*WDzb*

Example No. 3—Prover and Measure Information
Waterdraw Calibration—Small Volume Displacement Prover w/ External Detectors—Unidirectional Type

Date: ______________________ Report No. ______________________

Owner: ______________________ Operator: ______________________

Calibration Site: ______________________ Service Location: ______________________

Weather: ______________________ Sheet No. 1 of: ______________________

Prover Manufacturer: ______________________

Volume Identification: Downstream Volume — Type of Prover: Small Volume Prover Displacement Prover (UNI) w/ External Detectors w/ 1-Wall

Serial Number: ______________________ Material: 17-4 PH w/ Invar Rod

Cubical Coefficient of Expansion / Degree F:		*Gc*	=	0.0000180
Square Coefficient of Expansion / Degree F:		*Ga*	=	0.0000120
Linear Coefficient of Expansion / Degree F:		*Gl*	=	0.0000008
Modulus of Elasticity per psi		*E*	=	28500000
Outside Diameter of Prover	(inches)	*OD*	=	14.000
Wall Thickness of Prover	(inches)	*WT*	=	0.875
Inside Diameter of Prover	(inches)	*ID*	=	12.250

Field Standard Test Measures:

FILL	=	Number used to designate the order of recording the fills
REF	=	Reference number used to designate the measure being used
SEAL	=	Seal number installed by the calibration agency (e.g. NIST)
BMV	=	Base Measure Volume of field standard test measure @ 60 deg F
Gcm	=	Cubical coefficient of thermal expansion per degree F

REF No.	*BMV* cu. in.	Nominal gallons	SEAL No.	*Gcm*
1	3463.22	15	kkkk	0.0000265

Calib. Tech: ______________________ Company: ______________________

Witnessed by: ______________________ Company: ______________________

Witnessed by: ______________________ Company: ______________________

Example No. 3—Pass No. 1—w/ Computer
Waterdraw Calibration—Small Volume Displacement Prover w/ External Detectors—Unidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
1	1	Unidirectional	20 GPM	71.6	70.0	*Pp* = 35 psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	1	3463.22	17.3	3480.52	71.2	1.000050	1.000150	3481.2161
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM *WD* @ 60 DEGREES F	3481.2161
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000017
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000112
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	3480.7671

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 3—Pass No. 2—w/ Computer
Waterdraw Calibration—Small Volume Displacement Prover w/ External Detectors—Unidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
2	1	Unidirectional	10 GPM	72.2	70.0	*Pp* = 35 psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	1	3463.22	17.5	3480.72	71.8	1.000051	1.000159	3481.4510
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM *WD* @ 60 DEGREES F	3481.4510
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000017
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000112
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	3481.0019

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 3—Pass No. 3—w/ Computer
Waterdraw Calibration—Small Volume Displacement Prover w/ External Detectors—Unidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
3	1	Unidirectional	20 GPM	72.3	70.0	*Pp* = 35 psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	1	3463.22	17.2	3480.42	71.7	1.000077	1.000154	3481.2240
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

WDz	=	SUM *WD* @ 60 DEGREES F	3481.2240
CPSp	=	1 + [(*Pp* * *ID*) / (*E* * *WT*)]	1.000017
CPLp	=	1 / [1 – (0.0000032 * *Pp*)]	1.000112
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	3480.7750

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 3—Summary—w/ Computer
Waterdraw Calibration—Small Volume Displacement Prover w/ External Detectors—Unidirectional Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

PROVER CALIBRATION SUMMARY

Pass/Run No. I	=	3480.7671	@	20 GPM
Pass/Run No. II	=	3481.0019	@	10 GPM
Pass/Run No. III	=	3480.7750	@	20 GPM

Calculated Range Percent = 0.007%

Calculated Range Percent = [(MAX – MIN)/(MIN)] * [100]

Allowable Range Percent = 0.020 %

Note: Above summary in cubic inches @ 60 degrees F & 0 psig.
Note: Data obtained & calculations performed in U.S. Customary Units.

Solve for BASE PROVER VOLUME: AVERAGE Pass/Runs I, II and III

Cubic Inches	(16.387064 Cubic Centimeters)	@ 60°F & 0 PSIG	=	3480.8480
U.S. Gallons	(231 Cubic Inches)	@ 60°F & 0 PSIG	=	15.0686
Barrels	(9702 Cubic Inches)	@ 60°F & 0 PSIG	=	0.358776
Cubic Feet	(1728 Cubic Inches)	@ 60°F & 0 PSIG	=	2.01438
Liters	(1000 Cubic Meters)	@ 15°C & 101.325 kPa	=	57.0399
Cubic Meters	(1000 Liters)	@ 15°C & 101.325 kPa	=	0.0570399

Diameter of Displacer in Inches ____________ = ____________ % *ID* of Pipe

Calibrator's Name & Company Name ____________

13.4 OPEN TANK PROVER

The following example depicts the calculations and required documentation for an open tank prover waterdraw calibration.

EXAMPLE NO. 4
WATERDRAW CALIBRATION
VOLUMETRIC TANK PROVER—ATMOSPHERIC TYPE

(A) GENERAL PROVER INFORMATION

Waterdraw calibration date			________
Waterdraw calibration report number			________
Owner of meter prover			________
Location of meter prover			________
Manufacturer of meter prover			________
Serial number of meter prover			________
Type of meter prover			Atmospheric tank prover
Prover volume identification			Single volume with upper and lower neck/scales
Type of steel in meter prover			Mild carbon steel
OD	=	Outside Diameter of measuring chamber	96.000 inches
ID	=	Inside Diameter of measuring chamber	95.500 inches
WT	=	Wall Thickness of measuring chamber	0.250 inches
E	=	Modulus of Elasticity	30,000,000 per psig
Gc	=	Coefficient of cubical expansion	0.0000186 per degree F
Tb	=	Base Temperature for the prover	60 degrees F

(B) FIELD STANDARD TEST MEASURES

REF	=	Reference measure number	Ref 1	Ref 2
SEAL	=	NIST seal number on measure	aaaa	bbbb
NOM	=	Nominal volume in U.S. Gallons	500	500
BMV	=	Base Measure Volume (cubic inches)	115502.50	116202.20
Gcm	=	Coeff. cubical expansion per degree F	0.0000265	0.0000186
Tb	=	Base Temperature for the measure	60 degrees F	60 degrees F

(C) CALIBRATION PASS DATA

Calibration Run Numbers			Run No. I and Run No. II for *BPV*, w/ Check Run No. III afterwards		
Weather during each calibration pass			Weather		
Flow rate at filling of field standard measure			Run I @ 90 GPM, Run II @ 90 GPM and Run III @ 90 GPM		
SRu	=	Scale Reading on upper scale of prover (example assumes scales in U.S. gallons)			
SRl	=	Scale Reading on lower scale of prover (example assumes scales in U.S. gallons)			
Tp	=	Starting average prover temperature on waterdraw or ending average prover temperature on waterfill			
Pp	=	Atmospheric pressure	(0 psig)		
FILL	=	Measure fill number	w/each fill	Fill Numbers:	1 and 2 for each pass
REF	=	Measure reference number	w/each fill	Ref Numbers:	2 and 1 for each pass
BMV	=	Base Measure Volume	w/each fill	Cubic Inches:	115502.50 and 116202.20
SR	=	Scale reading on test measure	w/each fill	Plus or minus scale readings in cubic inches	
BMVa	=	Adjusted Volumes	w/each fill	*BMVa* = (*BMV* + *SR*)	
Ttm	=	Temperature test measure	w/each fill	Temperature in measure for each fill	

(D) CALCULATIONS FOR CALIBRATION PASS

CTDW	=	Table in Chapter 11.2.3	w/each fill	on any given pass	
CTSp	=	1+(*Tp*–*Tb*)*(*Gc*)	w/each fill	on any given pass	
CTSm	=	1+(*Ttm*–*Tb*)*(*Gcm*)	w/each fill	on any given pass	
CCTS	=	(*CTSm* / *CTSp*)	w/each fill	on any given pass	
WD	=	(*BMVa***CTDW***CCTS*)	w/each fill	on any given pass	
WD1	=	(*BMVa***CTDW***CCTS*)	w/ Fill No. 1	on any given pass	*WD1*
WD2	=	(*BMVa***CTDW***CCTS*)	w/ Fill No. 2	on any given pass	*WD2*
WDn	=	(*BMVa***CTDW***CCTS*)	w/ Fill No. n	on any given pass	*WDn*
WDz	=	*WD1* + *WD2* + ... + *WDn*	(sum of *WD*s from Fill Nos. 1, 2, ..., *n*) on each pass		*WDz*
CPSp	=	1 + (*Pp* * *ID*)/(*E* * *WT*)	for each pass	Note: *CPSp* = 1.000000	*CPSp*
CPLp	=	1 / [1–(0.0000032 * *Pp*)]	for each pass	Note: *CPLp* = 1.000000	*CPLp*
WDzb	=	*WDz* / (*CPSp* * *CPLp*)	(total cubic inches at *Tb* and *Pb*) on each pass		*WDzb*

Example No. 4—Prover and Measure Information
Waterdraw Calibration—Volumetric Tank Prover—Atmospheric Type

Date:	Report No.
Owner:	Operator:
Calibration Site:	Service Location:
Weather:	Sheet No. 1 of:

Prover Manufacturer: ______________________________

Volume Identification: Volumetric Tank ______________________ Type of Prover:Atmospheric Type

Serial Number: ______________________________ Material:Mild Carbon Steel

Cubical Coefficient of Expansion / Degree F:		*Gc*	=	0.0000186
Square Coefficient of Expansion / Degree F:		*Ga*	=	0.0000124
Linear Coefficient of Expansion / Degree F:		*Gl*	=	0.0000062
Modulus of Elasticity per psi		*E*	=	30,000,000
Outside Diameter of Prover	(inches)	*OD*	=	96.000
Wall Thickness of Prover	(inches)	*WT*	=	0.250
Inside Diameter of Prover	(inches)	*ID*	=	95.500

Field Standard Test Measures:

FILL	=	Number used to designate the order of recording the fills
REF	=	Reference number used to designate the measure being used
SEAL	=	Seal number installed by the calibration agency (e.g. NIST)
BMV	=	Base Measure Volume of field standard test measure @ 60 deg F
Gcm	=	Cubical coefficient of thermal expansion per degree F

REF No.	*BMV* cu. in.	Nominal gallons	SEAL No.
1	115502.50	500	aaaa
0.0000265			
2	116202.20	500	bbbb
0.0000186			

Calib. Tech:	Company:
Witnessed by:	Company:
Witnessed by:	Company:

Example No. 4—Run No. 1—w/ Computer
Waterdraw Calibration—Volumetric Tank Prover—Atmospheric Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
1	1	Atmospheric	90 GPM	70.2	n/a	*Pp* = 0 psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	116202.20	–300.0	115902.20	70.4	0.999976	1.000003	115899.7660
2	1	115502.50	–280.0	115222.50	70.6	0.999951	1.000091	115227.3388
3								
4								
5								
6								
7								
8								
9								
10								

WDz	=	SUM *WD* @ 60 DEGREES F	231127.1048
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000000
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000000
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	231127.1048

Prover:	Scale Reading Upper	(*SRu*)	in U.S. Gallons	=	1000.60
Prover:	Scale Reading Lower	(*SRl*)	in U.S. Gallons	=	–0.20
Prover:	Indicated Volume	(*SRu* – *SRl*)	in U.S. Gallons	=	1000.80

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 4—Run No. 2—w/ Computer
Waterdraw Calibration—Volumetric Tank Prover—Atmospheric Type

Date: ______________ Time: ____________ Report Number: ____________________

Sheet No: ______________ Of: ____________ Manufacturer: ____________________

Weather: ____________________________ Serial Number: ____________________

Owner/Operator: ______________________ Location: ____________________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
2	1	Atmospheric	90 GPM	72.5	n/a	*Pp* = 0 psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	116202.20	–300.0	115902.20	72.6	0.999987	1.000001	115900.8092
2	1	115502.50	–490.0	115012.50	72.8	0.999961	1.000106	115020.2054
3								
4								
5								
6								
7								
8								
9								
10								

The seals on the upper and / or lower scale(s) were broken, and the upper and / or lower scale(s) were adjusted as necessary, after two (2) consecutive runs were obtained within a range of 0.020%. Afterwards the upper and / or lower scale(s) were re-sealed in place.

WDz	=	SUM *WD* @ 60 DEGREES F	230921.0146
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000000
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000000
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	230921.0146

Prover:	Scale Reading Upper	(*SRu*)	in U.S. Gallons	=	1000.60
Prover:	Scale Reading Lower	(*SRl*)	in U.S. Gallons	=	0.60
Prover:	Indicated Volume	(*SRu* – *SRl*)	in U.S. Gallons	=	1000.00

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________________ Company: ____________________

Witnessed by: ____________________ Company: ____________________

Witnessed by: ____________________ Company: ____________________

Example No. 4—Run No. 3—w/ Computer
Waterdraw Calibration—Volumetric Tank Prover—Atmospheric Type

Date: ____________ Time: ____________ Report Number: ____________

Sheet No: ____________ Of: ____________ Manufacturer: ____________

Weather: ____________ Serial Number: ____________

Owner/Operator: ____________ Location: ____________

Pass	Page	Direction	Flow Rate	*Tp*	*Td*	Degrees F
3	1	Atmospheric	90 GPM	73.6	n/a	$Pp = 0$ psig

FILL	REF	*BMV*	*SR*	*BMVa*	*Ttm*	*CTDW*	*CCTS*	*WD*
1	2	116202.20	–300.0	115902.20	73.8	0.999973	1.000004	115899.5342
2	1	115502.50	–345.0	115157.50	74.0	0.999947	1.000118	115164.9845
3								
4								
5		This run made after re-sealing the upper and / or lower scale(s).						
6								
7		This run serves as a check run after re-sealing the upper and / or lower scales.						
8								
9								
10								

WDz	=	SUM *WD* @ 60 DEGREES F	231064.5187
CPSp	=	$1 + [(Pp * ID) / (E * WT)]$	1.000000
CPLp	=	$1 / [1 - (0.0000032 * Pp)]$	1.000000
WDzb	=	*WDz* / (*CPSp* * *CPLp*) @ 60 DEG F & 0 PSIg	231064.5187

Prover:	Scale Reading Upper	(*SRu*)	in U.S. Gallons	=	1000.60
Prover:	Scale Reading Lower	(*SRl*)	in U.S. Gallons	=	0.40
Prover:	Indicated Volume	(*SRu* – *SRl*)	in U.S. Gallons	=	1000.20

Note: Data obtained & calculations performed in U.S. Customary Units.

Calibration Tech: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Witnessed by: ____________ Company: ____________

Example No. 4—Summary—w/ Computer
Waterdraw Calibration—Volumetric Tank Prover—Atmospheric Type

Date: ____________________ Time: ________________ Report Number: ______________________________

Sheet No: __________________ Of: ________________ Manufacturer: ______________________________

Weather: ____ Serial Number: ______________________________

Owner/Operator: __________________________________ Location: ______________________________

PROVER CALIBRATION SUMMARY

	Target Volume		231000.0	cubic inches
Run I	*WDzb* obtained at 90 GPM		231127.1	cubic inches
	Scale Reading, upper (*SRu*)	(1000.60 gallons)	231138.6	cubic inches
	Scale Reading, lower (*SRl*)	(–0.20 gallons)	–46.2	cubic inches
	CPV1 = (*WDzb*) – (*SRu-SRl*) + (Target Volume)		230942.3	cubic inches
Run II	*WDzb* obtained at 90 GPM		230921.0	cubic inches
	Scale Reading, upper (*SRu*)	(1000.60 gallons)	231138.6	cubic inches
	Scale Reading, lower (*SRl*)	(0.60 gallons)	138.6	cubic inches
	CPV2 = (*WDzb*) – (*SRu-SRl*) + (Target Volume)		230921.0	cubic inches
	Allowable Range % between Runs I & II		0.020 %	
	Calculated Range % between Runs I & II		0.009 %	
	Average *CPV* (average Calibrated Prover Volume)		230931.7	cubic inches
	Percentage deviation from target volume:		–0.030 %	
	Upper Scale moved UP (+) or DOWN (–) in cu. inches		50.0	cubic inches
	Lower Scale moved UP (+) or DOWN (–) in cu. inches		–18.3	cubic inches
	Calibrated Prover Volume (*CPV*) at new scale positions		231000.0	cubic inches
Run III	*WDzb* obtained at 90 GPM in cubic inches		231064.5	cubic inches
	Scale Reading, upper	(1000.60 gallons)	231138.6	cubic inches
	Scale Reading, lower	(0.40 gallons)	92.4	cubic inches
	CPV3 = {*WDzb*} – (*SRu-SRl*) + {Target Volume}		231018.3	cubic inches
	Allowable range % from target volume		0.010 %	
	Calculated range % from target volume		0.008 %	
	Calculated range percent: [(MAX – MIN)/(MIN)] * [100]			

Note: Above summary in cubic inches @ 60 degrees F & 0 psig.
Note: Data obtained & calculations performed in U.S. Customary Units.

Solve for BASE PROVER VOLUME: *BPV* is determined from *CPV* at new scale positions after Runs I and II, and is confirmed by Check *CPV* on Run III.

Cubic Inches		@ 60°F & 0 PSIG	231000.0	cubic inches
U.S. Gallons	(231 cubic inches per gallon)	@ 60°F & 0 PSIG	1000.00	U.S. Gallons

Calibrator's Name & Company Name ______________________________

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