Manual of Petroleum Measurement Standards Chapter 4.9.1

Introduction to the Determination of the Volume of Displacement and Tank Provers

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Introduction

Provers are precise, volumetric standards that are used to verify the accuracy of liquid flow meters. Both displacement and tank provers are used to prove a meter to obtain its meter factor. The base volume of a displacement or tank prover, determined by calibration, is an essential requirement in the determination of these meter factors. The accuracy of a meter factor is limited by several considerations, as shown below.

— equipment performance;

— observation errors;

— prover volume calibration errors;

— calculation errors.

Prover volumes used to calibrate meters are determined by calibration and not by theoretical calculation. Volumetric provers shall have an exact reference volume determined by a recognized method of calibration. Techniques for the determination of this reference volume include the waterdraw, master meter, and gravimetric methods of calibration. API *MPMS* Chapters 4.9.2, 4.9.3, and 4.9.4 are used to accurately determine the calibrated volume of meter provers.

U.S. Customary and Metric (SI) Units

This standard presents U.S. Customary (USC) units. Where International System (SI) are not presented, they can be referenced in Annex D. Implementation of either system of units in a calibration can be limited by a method's individual standard. The system of units to be used is typically determined by contract or regulatory requirements.

National Metrology Institutes

Throughout this document, issues of traceability are addressed by references to the National Institute of Standards and Technology (NIST). However, other appropriate national metrology institutes can be referenced.

Safety Considerations

There is no intent to cover safety aspects of conducting the work described in this standard, and it is the duty of the user to be familiar with all applicable safe work practices.

Introduction to the Determination of the Volume of Displacement and Tank Provers

1 Scope

Chapter 4, Section 9 covers all the procedures required to determine the field data necessary to calculate a base prover volume (BPV) of either displacement provers or volumetric tank provers. It will enable the user to perform all the activities necessary to prepare the prover, conduct calibration runs, and record all the required data necessary to calculate the base volumes of displacement and tank provers. Evaluation of the results and troubleshooting of many calibration problems are also discussed.

This component, Chapter 4, Section 9, Part 1, is the introduction, and contains all those relevant aspects that are general in nature, yet essential and applicable to all the different methods of calibration. Therefore, each subsequent part, which describes a specific method of prover calibration, shall be used with Part 1. Together, the two parts contain all the information that is essential to complete the required method of calibration.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API *MPMS* Chapter 4.2, *Displacement Provers*

API *MPMS* Chapter 4.7, *Field Standard Test Measures*

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

API *MPMS* Chapter 4.9, *Methods of Calibration for Displacement and Volumetric Tank Provers Part 2—Determination of the Volume of Displacement and Tank Provers by the Waterdraw Method of Calibration*

API *MPMS* Chapter 4.9, *Methods of Calibration for Displacement and Volumetric Tank Provers Part 3—Determination of the Volume of Displacement Provers by the Master Meter Method of Calibration*

API *MPMS* Chapter 4.9, *Methods of Calibration for Displacement and Volumetric Tank Provers Part 4—Determination of the Volume of Displacement and Tank Provers by the Gravimetric Method of Calibration*

API *MPMS* Chapter 5 (all sections), *Metering*

API *MPMS* Chapter 12.2.4, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors, Part 4—Calculation of Base Prover Volumes by Waterdraw Method*

3 Terms and Definitions

For the purposes of this document, the following terms and definitions apply. Terms of more general use may be found in API *MPMS* Chapter 1, *Online Terms and Definitions Database*.

3.1
base prover volume
BPV
The volume of the prover at base conditions as shown on the prover calibration certificate.

3.2

block and bleed valve

A high integrity valve with double seals and provision for determining if either seal leaks.

3.3

calibration certificate

A report documenting the calibration of a measurement device, such as a meter prover, thermometer, or pressure instrument, and its traceability to a national metrological institute (e.g., National Institute of Standards and Technology for the U.S.).

3.4

calibration run

One run conducted during the calibration of a displacement or tank meter prover.

3.5

designated reference device

A single reference device to which other reference or working devices are verified.

3.6

pass

A single movement of the displacer in a displacement prover that activates the start-stop detectors.

3.7

prover calibration certificate

A document package stating the base prover volume (BPV) that includes the physical and run data used to calculate the BPV, calibration certificates, and instrumentation verification documents.

3.8

round trip

The combination of a single pass of the displacer in one direction (e.g., forward) followed by a single pass of the displacer in the opposite direction (e.g., back) in a bidirectional displacement prover.

3.9

reference device

A certified and traceable measurement device to which other similar devices are verified or calibrated.

3.10

working device

A certified or non-certified measurement device used for operational measurements. These devices are routinely verified or calibrated to a reference device.

3.11

verification certificate

A document indicating the results of a comparison of instrumentation of the same type used in the calibration method.

4 Applications

A prover calibration is initially performed at the manufacturing plant where the prover is built. A prover shipped and installed with the measuring section intact may not require a field calibration. After the initial calibration, the frequency shall be determined according to API *MPMS* Chapter 4.8. The frequencies normally range from one to a maximum of five years, or could be as short as a few months based upon the calculation required by API *MPMS* Chapter 4.8.

Consideration of the following items will help to establish the possible loss exposure and measurement risk, and will help to determine a required frequency of calibration for all provers:

— the total yearly value of each product metered;

— volume through the metering system associated with the prover between prover calibrations;

— number of meters regularly proved by the prover and their frequency of proving;

— service conditions and properties of products being metered and proved;

— whether the prover is portable or stationary;

— the different types of products being metered;

— the range of properties of liquids being metered;

— the required yearly maintenance and repair;

— the overall condition of the prover, including detectors and sphere displacer.

5 Types of Meter Provers

5.1 General

The following describes the most common types of provers. See other sections of API *MPMS* Chapter 4[1] for additional detail on prover design.

5.2 Displacement Type Unidirectional Provers with Free Displacers

These types of unidirectional provers may be subdivided into the following two categories depending on the manner in which the displacer is handled:

— unidirectional sphere provers with electromechanical detectors and manual return;

— unidirectional sphere provers with electromechanical detectors and circulating return.

The manual-return unidirectional prover, sometimes referred to as the measured distance, is an elementary form of an in-line prover that uses a section of pipeline as the prover section. Prover detector switches that define the calibrated volume of the prover section are placed at selected points along the pipeline. A displacer-launching device is placed upstream from the prover section, and receiving facilities are installed at some point downstream from the prover section. Conventional launching and receiving scraper traps are usually used for this purpose. To make a proving run, a displacer is launched and allowed to displace the reference volume before being received downstream and manually transported back to the launching site. This type of prover is no longer in common use.

The circulating-return unidirectional type prover has evolved from the prover described above. In a unidirectional ball displacer type prover design, the piping is arranged so that the downstream end of the loop crosses over and above the upstream end of the looped section. The interchange is the means by which the displacer is transferred from the downstream to the upstream end of the loop without being removed from the prover. The displacer detectors are located inside the looped portion at a suitable distance from the interchange. Unidirectional prover loops may be automated or manually operated.

5.3 Displacement Type Bidirectional Provers with Free Displacers

— bidirectional sphere provers with electromechanical detectors;

— bidirectional piston provers with electromagnetic detectors and check valves;

— bidirectional piston provers with electromechanical detectors and check valves.

There are three types of bidirectional provers: the sphere prover with mechanical detectors; the piston prover with magnetic detectors and check valves; and the piston prover with mechanical detectors and check valves. These types of bidirectional provers have a length of pipe through which the displacer travels back and forth, actuating a detector switch at each end of the calibrated section. Suitable supplementary pipework and a reversing valve or valve assembly that is either manually or automatically operated make possible the reversal of the flow through the prover. The main body of the prover is often a straight piece of pipe, but it may be contoured or folded to fit in a limited space or to make it more readily mobile. A sphere is used as the displacer in the folded or contoured type; a piston or sphere may be used in the straight-pipe type.

A round trip of the displacer in a bidirectional displacement prover consists of the combination of one OUT pass followed by one BACK pass of the displacer in a bidirectional meter prover. The OUT pass refers to the flow of the liquid in the FORWARD direction while the displacer moves away from the HOME position. The BACK pass refers to the flow of the liquid in the REVERSE direction while the displacer returns to the HOME position. The terms “left to right” and “right to left” are also used to name the pass directions. By convention, these directions are determined by facing the 4-way valve while standing near the 4-way valve but away from the prover skid. See Figure 1 for an illustration of the “left” and “right” sides of a bidirectional meter prover.

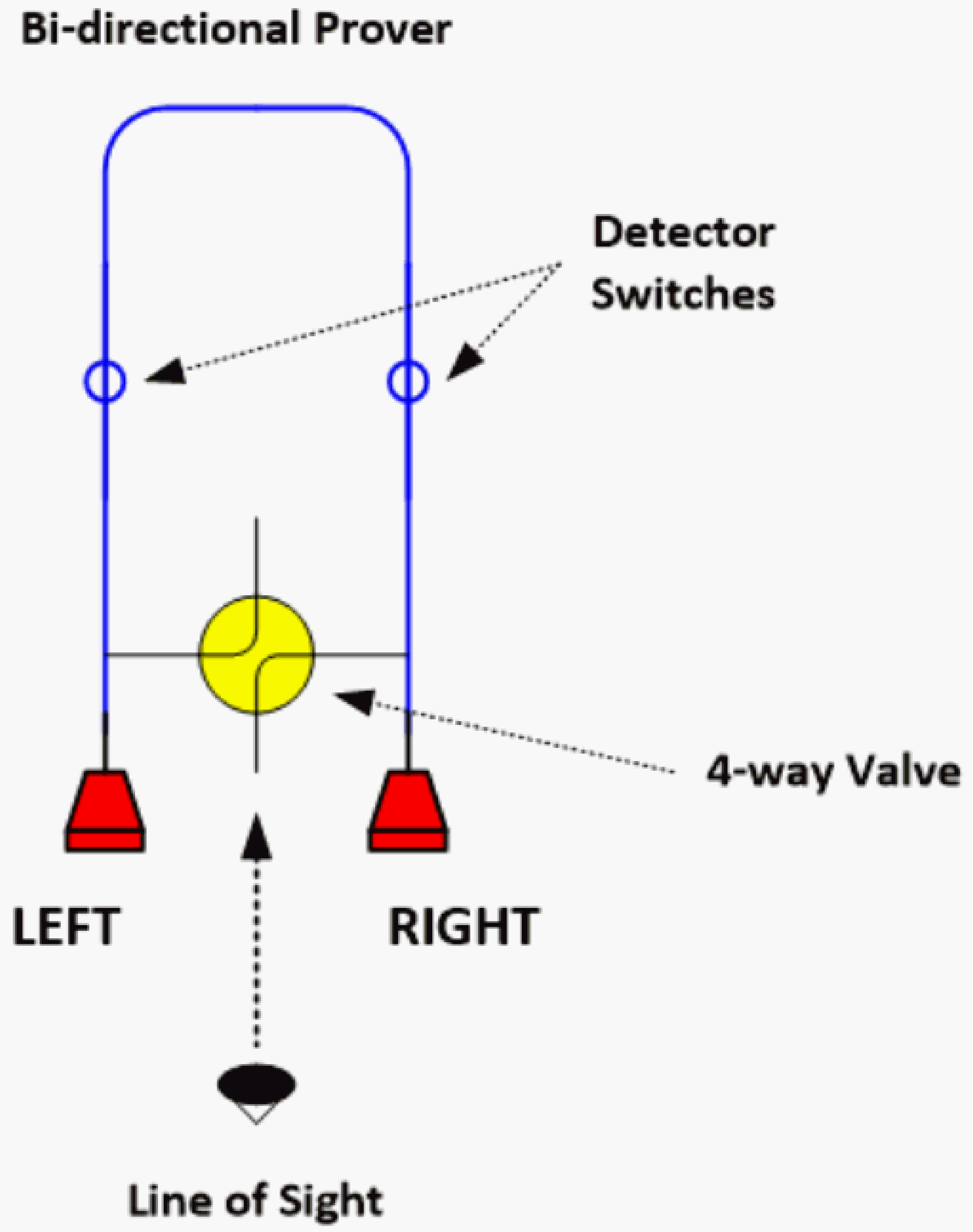

Figure 1—Bidirectional Prover Orientation of “Left” and “Right”

5.4 Displacement Type Provers with Captive Displacers

5.4.1 Unidirectional Piston Provers with External Optical Detectors

A captive displacer type prover has a shaft attached to its displacer. The area displacement of the shaft is constant. Thus, a prover with a captive displacer and a shaft attached to only one side of the displacer will have different upstream and downstream volumes. If shafts are attached to both sides of the displacer and they have equal cross-sectional area displacement, the upstream and downstream volumes are equal, and therefore do not require separate upstream calibrations. There may be more than one detector and/or shaft attached to the captive displacer.

Since these type provers have externally mounted optical detectors, the thermal effect on the detector mounting might not be the same as the effect on the measurement area (prover barrel). For example, if both the prover barrel and the mounting that defines the linear distance between the detector(s) were the same metal, the thermal effects would be the same. In most cases, the prover barrel is one type of steel while the detector(s) mounting (which defines the linear distance between the detector(s)) is another type of steel. Different types of steel have different thermal coefficients of expansion, and their expansion has to be calculated independently. In terms of a prover calibration, the main effect is that it is necessary to obtain both a prover volume and the detector mounting temperature.

5.5 Displacement Type Provers with Multiple Volumes

If a prover has multiple switches, each set of switches determines a stand-alone and independent volume. If more than one calibrated volume is to be defined, the volumes shall be established with independent calibrations when using the waterdraw or gravimetric method. If the master meter method is used, data for the individual calibrated volumes can be collected simultaneously with proper equipment and procedures.

5.6 Atmospheric Tank Type Provers

An atmospheric tank prover is a volumetric vessel with an upper neck, upper sight glass, upper scale, and an upper and lower cone usually separated by a cylindrical section. Different types are identified by the way in which their bottom “zero” is defined. Atmospheric tank provers are described below:

— Bottom-weir type: This prover has a bottom neck beneath the lower cone. The bottom neck may or may not have a sight glass and scale, but in any case, it has a fixed bottom “zero” defined by the weir.

— Dry-bottom type: This prover usually does not have a bottom neck under the lower cone. The closed bottom drain valve defines the bottom “zero,” just as on a field standard test measure.

— Wet-bottom type: This prover has a bottom neck beneath the lower cone. The bottom neck always has a sight glass and scale. The bottom “zero” is defined by the “zero” on the scale. In practice, readings above and below the “zero” in the lower neck are common.

6 Equipment

6.1 Launching Chambers and Transfer Chambers

With both unidirectional and bidirectional provers, an area is provided in which the displacer can rest when not in use. With bidirectional ball displacer type meter provers, this space is defined as a launching chamber. Bidirectional provers using sphere displacers require launching chambers at both ends of the prover pipe. Piston type bidirectional provers do not require expanded launch chambers at either end of the prover pipe because the flowing stream does not go around the piston, but is diverted upstream of the launch chambers by means of check valves. On unidirectional meter provers, a transfer chamber is used in combination with one or more valves to store the sphere away from the flowing stream, and to provide a means to relaunch the displacer when required.

6.2 Unidirectional Sphere Interchanges

The sphere interchange provides a means for transferring the sphere from the downstream end of the proving section to the upstream end. Transfer of the sphere may be accomplished with several different combinations of valves or other devices to minimize bypass flow through the interchange. A leak-tight seal between the upstream and downstream sides is essential at the moment the displacer actuates the first detector, while it travels between the detectors, and when it actuates the second detector in any given pass. The seal shall be verified to validate that leakage does not occur during the pass. An additional length of pipe is provided in the prover to ensure that the interchange is fully sealed before the sphere contacts the first detector switch. This length of pipe is known as the pre-run section and is included in all prover construction based on the design flow rate.

6.3 Four-Way Valves

The four-way diverter valve is used on bidirectional provers to change the flow direction through the prover. It is designed to handle low-pressure differentials and has a double block and bleed feature to verify the sealing integrity of the valve. A leak-tight seal is essential at the moment the displacer actuates the first detector in any given pass, while it travels between the detectors, and when it actuates the second detector in any given pass. The seal shall be verified to validate that leakage does not occur during the pass. An additional length of pipe is provided in the prover, prior to the detector switch, to allow the sphere to travel while the four-way valve is in operation and to ensure that the four-way valve is fully sealed before the sphere contacts the first detector switch. This length of pipe is known as the pre-run section and is included in all prover construction based on the design flow rate.

6.4 Displacers

6.4.1 General

The displacer is used to displace the volume between the detectors. It shall be sized to create a leak-free seal between the displacer and the prover wall. The volume of the prover is defined by detector switch actuations. There are three common types of displacers.

6.4.2 Sphere Type Free Displacers

The most common sphere displacer is the inflatable type. It has a hollow center with one or more valves used to inflate the sphere. A glycol/water mixture is often used to fill the sphere; however, water alone may be used in warm climates. The sphere is typically inflated to ~2 %–5 % larger than the inside diameter of the calibrated section of the prover.

The most common elastomers used in the construction of sphere displacers are urethane, nitrile, and neoprene. No one material is ideal for all applications or fluids.

6.4.3 Piston Type Free Displacers

Piston displacers are used in specially designed bidirectional provers, and are usually lightweight and made of aluminum or nonmagnetic stainless steel. These pistons are cylindrical in shape, have seals, have wear-rings at each end, and usually have an exciter ring. An exciter ring is a magnetic device fitted into the piston and designed such that the magnetic field will activate a proximity type detector switch as the piston passes beneath it. Teflon and polyurethane are the most commonly used elastomers in the construction of piston seals.

6.4.4 Piston Type Captive Displacers

Captive displacers are typically constructed of stainless steel with polymer-based elastomeric seals.

The displacer is attached to a shaft that passes to the outside of the prover barrel. The shaft(s) is normally used to move the displacer to the launching position and activate the detector switches. The displacer has an internal poppet valve that opens at the end of a pass. This allows for an unimpeded flow through the displacer at the end of the pass or while returning the displacer to the launching position. The poppet valve is equipped with elastomeric seals to prevent leakage across the displacer during a pass.

6.5 Pre-runs

On any displacement prover, it is necessary that the liquid stream be stable and that the interchange or four-way valve be sealed before the displacer actuates the first detector switch for any given pass. See API *MPMS* Chapter 4.8 for more information.

6.6 Prover Detector Switches

6.6.1 General

A detector switch is a precision device mounted on a prover; it is used to detect the passage of a displacer. The calibrated volume of a prover is the amount of fluid that is displaced between two detector switch positions. Additional detector switches may be used if more than one calibrated volume is desired on the same prover, or they can also be used to signal the entrance of a displacer into the sphere resting chamber. Several types of detector switches are described below. The calibrated volume shall be associated with the unique detector pair used to determine that volume.

6.6.2 Electromechanically Actuated Detector Switches

The mechanical type of detector switch is used primarily with an elastomeric sphere displacer, but there are applications where they are used with piston displacers and are operated when the displacer contacts a rod or ball protruding into the prover pipe. At the point of operation, a switch is closed or opened by means of a mechanically or magnetically driven contact.

Mechanically actuated detectors may or may not be pressure balanced. Pressure-balanced detectors have ports or passages that allow pressure to be equally distributed on the switch rod, thereby offsetting the effect of pressure on the activation of the detector.

6.6.3 Proximity Type Magnetically Actuated Detector Switches

This type of detector switch is used only with piston displacers and is mounted externally, with no parts protruding into the prover pipe. An exciter ring on the nonmagnetic piston displacer actuates the detector switch mechanism as it passes beneath the proximity type detector switch.

6.6.4 Optically Actuated Detector Switches

Conventional design of an optical detector has a light source, together with a photoelectric detector cell, mounted opposite each other on a small metal base plate. In normal operations, the light source shines directly into the photoelectric cell until the light beam is interrupted by a lever or plate mounted to a moving shaft on the displacer. Breaking of the light beam causes the detector switch to operate.

6.7 Valves, Relief Valves, Drains, and Vents

The unidirectional prover sphere handling interchange, the bidirectional prover four-way valve, all valves located between the calibrated section of the prover and the calibration unit, and any valve in a line bypassing the prover shall seal without any internal or external leakage when in a closed position and have a means to verify the seal during calibration. Any valve or line that allows product to escape will cause serious errors.

Double block and bleed valves are used on provers where leak detection is essential. These valves are double seated with a space between the two seats that is connected to a small bleed valve. By opening this bleed valve, the operator can make a positive check that the main valve is not leaking. Any leakage across either of the valve seats will reveal itself through the bleed. In some double block and bleed systems, leakage is allowed to pass freely through the bleed to a location where it can be seen flowing; in other valves, the bleed is connected to a pressure gauge so that rising or falling pressure is the indication of leakage.

The prover and all the associated piping involved during the calibration may contain relief, drain, and vent valves. All of these valves may normally discharge into the drainage system and can easily hide an unknown source of leakage. All of these valves shall have a means to visually verify that no leakage is occurring or they are to be isolated during each calibration run.

All valves located on the prover system, the associated piping or hoses connecting the calibration unit, and to the final connections of the calibration device (test measure, master meter, or scale) that are operating in the open position shall be monitored for any signs of external leakage.

Any leak during a calibration pass is a cause for immediate suspension of the test. Leak repair(s) shall be performed before the test can be repeated. Leaks include displacer leaks, interchange leaks, four-way valve leaks, drain valve leaks, vent valve leaks, relief valve leaks, and external leaks such as hose leaks, connection leaks, and solenoid valve leaks.

6.8 Hoses, Pumps, and Connections

All hoses and connectors used shall be leak free, suitable for the liquid used in the calibration, and suitable for the maximum pressures expected throughout the calibration. Hoses used for calibration should be wire-wound to prevent collapse and minimize any inflation or deflation due to changes in pressure. The total length of hoses in use should be as minimal as practical to minimize the volume of liquid contained in the hoses.

For waterdraw or gravimetric calibrations, the pump (or pumps) used to circulate water throughout the system during the calibration should be in good working condition with no leaks. An electric motor-driven centrifugal pump works best, since the flow rate can be easily varied or stopped with the outlet pressure remaining relatively low. Pump capacities of 20 GPM to 100 GPM are typical; however, higher-capacity pumps are sometimes used when larger field standard test measures are used in the calibration. System downstream pressures from 20 psig to 60 psig are normally sufficient.

For master meter calibrations, the pumps that circulate liquid throughout the system during the calibration should be in good working condition with no leaks. The pump(s) should be compatible with the liquid used for the calibrating medium. The lowest pressure at any part of the system shall be a minimum of 1.5 times the equilibrium vapor pressure at operating temperature of the liquid used in the calibration. When using a circulating system method, an electric motor-driven centrifugal pump works best since the flow rate can be easily varied or stopped with the outlet pressure remaining relatively low.

6.9 Solenoid Valves and Automation

6.9.1 General

Solenoid valves, programmable logic controllers (PLCs), and flow computers are tools that can be used in prover calibrations.

6.9.2 Solenoid Valves

Solenoid valves, used in waterdraw and gravimetric calibrations, are a combination of an electromagnetic plunger and an orifice to which a disc or plug can be positioned to either restrict or completely shut off a flow. Orifice closure in an electromagnetically operated solenoid occurs when a switch is actuated. Typical orifice sizes range from 0.09375 ($^3/_{32}$) to 0.25 ($^1/_4$) inch.

Solenoid valves may be two-way or three-way acting. The speed and repeatability of solenoid actuation can affect calibration results. For this reason, a direct acting solenoid valve is recommended for use in a waterdraw or gravimetric waterdraw calibration. Pilot-operated solenoids are not recommended due to slower actuation times and actuation times that change with changes in line pressure.

Solenoid valves are actuated by a detector and are usually arranged to stop the water flow to drain and divert it into the test measure, or vice versa. The use of a solenoid valve reduces the uncertainty in valve closure to stop the test measure filling when the displacer contacts the second detector. Other uses of the solenoid valve during the prover calibration permit the recording of the stop/start sequence at the same exact repeatable conditions every time. Solenoid valves control the final approach of the displacer so that it arrives at the same exact position each time that it actuates the detector.

6.9.3 Automation

Solenoid valves, PLCs, and flow computers can be used to automate prover calibrations. They can aid in calibration and provide assistance in locating the position of the displacer, sometimes by means of visible or audible signals. It is common industry practice to automate these processes.

6.9.4 Connecting Detector Switches to the Solenoid and/or Logic Circuit

Suitable electrical interfacing should be used between the prover calibration logic circuit and the prover displacer detector switches to ensure proper operation. This is to provide isolation and suitable levels of power to protect all contacts and detector circuits. This applies to all types of displacement provers. Consult the prover manufacturer for the correct logic circuit and wiring instructions.

6.10 Field Standard Test Measures

Field standard test measures used for the waterdraw calibration method are stainless steel vessels fabricated to specific design requirements. Test measures typically range in volume from one gallon to 1000 gallons, with 500 gallons being the largest size in regular use. Test measures used for prover calibration shall be constructed, certified, and used in accordance with API *MPMS* Chapter 4.7.

6.11 Master Meter

The master meter is a meter used for master meter prover calibration. The master meter shall be installed and operated in accordance with API *MPMS* Chapter 5 and API *MPMS* Chapter 4.9.3. Pressure and temperature instrumentation shall be installed on the master meter run.

6.12 Master Prover

A master prover shall be designed and sized to work in conjunction with the master meter in accordance with API *MPMS* Chapter 4.2. The master prover shall have a calibrated volume that was determined using the waterdraw or gravimetric method. The master prover shall be equipped with pressure and temperature instrumentation on the prover. All drain and vent valves on the master prover shall either be of the block and bleed type or have other means for checking leakage.

6.13 Calibration Unit

Typically, the prover calibration equipment is mounted on a truck or trailer. It is important that the calibration equipment be rigidly constructed and securely mounted on the truck or trailer to prevent deformation or damage during transportation, usage, or storage.

6.14 Gravimetric Equipment

The equipment used in the gravimetric method is the same as for the waterdraw method found in API *MPMS* Chapter 4.9.2 except that the test measure(s) is replaced by a weighing system. A weighing system consists of a weigh scale(s), certified test weight(s) and a container(s) to hold the calibration water. Details can be found in API *MPMS* Chapter 4.9.4.

7 Temperature and Pressure Measurements

7.1 General

Numerous temperature and pressure measurements are required in a calibration. All readings shall be recorded to the specific discrimination level required by each calibration method as specified in the associated section of API *MPMS* Chapter 12.2.4. This standard allows the use of digital or analog measurement devices as long as they meet the requirements as stated below.

For the purposes of this standard, two classes of measurement devices may be used in a prover calibration: certified and non-certified. A certified device is one that has a valid calibration certificate. A valid certificate is one in which the date of use is within one year of the certificate date. A working device is an instrument used to take measurements during the calibration. It can be either certified or non-certified. All instruments used in the calibration shall be verified per 7.4 and 7.6.

All devices and calibration certificates used for prover calibration shall have unique identifiers (serial numbers, ID numbers, Company IDs) and be on site and available at the time of the prover calibration.

7.2 Measurement Devices and Methods of Use

There are three methods to capture representative measurements for the prover calibration. All methods involve verifying multiple devices before and after the calibration. The devices used shall meet the criteria of this standard.

— **Designated reference certified and working device method**

This practice is to define one certified device to be the designated reference measurement device. This designated device would then be used to verify the "working" measurement devices used to take readings for the calibration. It is recommended that this one designated device not be used in the calibration.

— **Multiple certified devices**

This practice is to use multiple certified measurement devices for taking readings during the calibration. These devices shall be verified against the designated reference device and to each other.

— **Combination of certified devices and working devices method**

This practice is to use any combination of certified and working measurement devices for taking readings during the calibration. These devices shall be verified against the designated reference device and to each other.

7.3 Temperature Measurements

For waterdraw and gravimetric methods, prover temperature shall be taken downstream of the prover displacer. For the master meter method, the location of the temperature measurement device(s) shall be such as to ascertain the average temperature of the liquid in the field prover, the master prover, and the master meter.

When using glass stem thermometers, partial immersion type shall be used. Total and full immersion type shall not be used.

Glass thermometers used as working devices shall have scales etched in increments no greater than 0.2 °F (0.1 °C) and shall be read to the nearest 0.1 °F (0.05 °C). A certified glass thermometer shall display in increments of no greater than 0.1 °F (0.05 °C). Refer to API *MPMS* Chapter 7[2] for more information.

Reference and working digital thermometers shall have a display resolution of no greater than 0.01 °F (0.01 °C), as applicable. Temperature measurements from a reference or working digital thermometer shall be rounded to the nearest 0.1 °F (0.05 °C). Refer to API *MPMS* Chapter 7[2] for more information.

Certified thermometers (electronic or glass) can be used to verify working temperature devices or to take readings during the calibrations. Where working thermometers are used to take temperature readings, they shall be verified and documented with the certified temperature device prior to and after the prover calibration.

7.4 Verification of Temperature Devices

All temperature devices used in the calibration shall be verified before and after the prover calibration. All devices shall agree with each other and with the designated reference device within a range of 0.1 °F (0.05 °C) at a single temperature point within the expected temperature range of the calibration.

The comparison of temperature devices shall be recorded and included in the prover certification documentation. The date, time, and serial number of designated devices, ID numbers of working devices, and the indicated temperature of each device shall be recorded. Spare devices may be compared at the same time to allow the calibration to continue in the case of failure of any of the temperature devices used during the calibration of the prover. See the example provided in Figure 2[1] .

Prover ID: Prover 1						
Prover Calibration Date/Time: NOV 14, 2015 @ 10:00 am						
Prover Calibration Location: KenSteveMark Station						
Temperature range of Calibration: 51.0 to 53.0						
Comparison Method: Reservoir Water						
Device ID	**Calibration Date**	**Certified (C) or Non-Certified (NC) Device**	**Working (W) or Reference (Ref)**	**Comparison Location**	**Comparison Before Calibration**	**Comparison After Calibration**
Device 1	Nov 1, 2015	NC	W	Reservoir	51.1	51.8
Device 2	Nov 1, 2015	NC	W	Reservoir	51.0	51.8
CTD5678	Nov 30, 2014	C	Ref	Reservoir	51.1	51.7
CTD1234	Nov 30, 2014	C	Spare	Reservoir	51.1	51.8

Figure 2—Field Verification Form for Thermometers

7.5 Pressure Measurements

For waterdraw and gravimetric methods, prover pressure measurements shall be taken downstream of the prover displacer. For waterdraw and gravimetric calibrations, a pressure measurement is required downstream of the displacer and before the manifold prior to the water entering the test measures or container. Because of the very low flow rate when the water is flowing only through the solenoid valve and the resulting minimal pressure drop at that time, it is acceptable to install the pressure-measuring device on the calibration unit. For the master meter method, the location of the pressure-measurement devices shall be such as to ascertain the average pressure of the liquid in the field prover, the master prover, and the master meter.

Pressure-measurement devices for all methods shall have an accuracy +/− 1.0 psig (6.9 kPag, 0.07 barg) or better at any indication point.

All pressure readings shall be recorded to the nearest whole number regardless of the discrimination of the indication.

7.6 Verification of Pressure Devices

When multiple pressure devices are used in the calibration, they shall be verified against each other before and after the prover calibration. All pressure devices shall agree with each other and with the designated reference device within 1 psig (6.9 kPag, 0.07 barg). The comparison of pressure devices shall be recorded and included in the prover certification documentation. The date, time, and serial number of certified devices, ID numbers of working devices, and the indicated pressure of each device shall be recorded. Spare devices may be compared at the same time to allow the calibration to continue in the case of failure of any of the pressure devices used during the calibration of the prover.

[1] This is an example for illustration purposes only. Each company should develop its own approach. It is not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

8 Preparation Before Calibration

It is highly recommended that the user observes the same care in preparation for the calibration as that observed during the calibration. The time and effort spent in preparation can exceed that expended in the actual calibration, but experience has shown that thorough preparation will minimize the total time to achieve a representative prover volume by eliminating the time spent troubleshooting a failed calibration. Preparation details are included in the standard applicable to the calibration method to be used (API *MPMS* Chapters 4.9.2, 4.9.3, or 4.9.4) and should be followed.

9 Documentation and Record Keeping

Data for calculations may be recorded manually or by automated means.

The results, whether recorded manually or by automated means, shall be verified against the data input for the prover calibration certificate prior to accepting the results. See API *MPMS* Chapter 21.2[3], as applicable, for guidance when automation is used.

In case of discrepancies or errors discovered between the observed data and printed data, corrections shall be made prior to finalizing the prover calibration certificate.

All items described in Annex C shall be included in the prover calibration certificate.

The prover calibration certificate shall include the calibration date and the base prover volume prominently displayed on the front page. See Annex C for a detailed list of items to be included in the prover calibration certificate for each method.

Annex A
(informative)

Troubleshooting Guidelines

This annex is provided for general information to assist in troubleshooting. The guidelines are outlined below.

a) **General Conditions**

1) Calibration liquids

   i. air in the flowing system (including water aeration);

   ii. aerated water in a field standard test measure;

   iii. hydrocarbons or detergents in the system when water is the calibration liquid.

2) Leaks in system

   i. internal:

      1) sphere interchanges;

      2) four-way valves;

      3) manifold prover bypass valves;

      4) manifold meter bypass valves;

      5) drain communication lines;

      6) displacer;

      7) displacer poppet valve;

      8) displacer seal;

      9) piston displacer assembly.

   ii. external:

      1) drain valves;

      2) vent valves;

      3) relief valves;

      4) prover and manifold flanges;

      5) overflow of field standard test measure;

      6) hoses and connections.

3) Temperature

i. instability;

ii. non-representative;

iii. outside of calibration limits.

4) Pressure

i. instability;

ii. non-representative;

iii. outside of calibration limits.

5) Flow

i. instability;

ii. non-representative;

iii. outside of calibration limits;

iv. cavitation.

b) **Equipment Malfunction or Damaged Equipment**

1) Valves

i. isolating valves;

ii. solenoid valves;

iii. manifold valves;

iv. drain valves;

v. vent valves;

vi. relief valves;

vii. bleeder valves;

viii. seal sensing valves.

2) Displacers

i. free displacers:

1) spheres:

a) state of roundness;

b) improperly filled;

c) improperly sized;

d) state of liquid fullness;

e) excessive wear on the ball.

2) pistons:

a) electromagnetic balance;

b) less than minimum length;

c) bent or other physical damage;

d) excessive wear on the seals.

ii. captive displacers:

1) pistons with shafts:

a) piston with shaft on one end;

b) piston with shaft on both ends.

3) elastomer materials of displacer seals and valve seals:

i. inappropriate for the calibration liquid;

ii. inappropriate durometer;

iii. inappropriate temperature or pressure range;

iv. excessive wear on the seals.

4) field standard test measures:

i. improper draining procedure per API *MPMS* Ch. 4.7;

ii. aerated water in a field standard test measure;

iii. hydrocarbon contamination on the walls of the field standard test measure;

iv. dent or other physical damage;

v. seals on the sight glass scale assembly;

vi. seals on the drain valves;

vii. identification tags from NIST or another national metrology institute;

viii. contamination inside the container:

1) wax;

2) dirt;

3) oil;

4) grease;

5) other physical objects.

   ix. state of level when measure is full of water;

   x. unstable legs;

   xi. trapped bubbles of air on cone or bottom of sight glass of measure (thumping);

   xii. cleanliness of the sight glass causing an ill-defined meniscus.

5) master meter:

   i. physical damage;

   ii. damaged master meter.

6) field or master prover:

   i. physical damage;

   ii. damage to master prover;

   iii. coating loss, blistering, or flaking;

   iv. damage to or deterioration of the internal surfaces of the prover;

   v. damaged or leaking sphere interchange;

   vi. damaged or leaking four-way valve;

   vii. damaged or leaking poppet valve.

7) malfunctioning prover detector switches:

   i. sticking switches;

   ii. missed actuations;

   iii. weak or fluctuating magnetic fields;

   iv. hysteresis and mismatched actuations in opposite directions;

   v. maintenance or readjustments between calibrations;

   vi. mismatching of component parts of detector switch set assemblies.

8) gravimetric equipment:

   i. scales or balances;

   ii. weighing container;

   iii. reference weights;

   iv. damaged weighing device or weight standards.

9) temperature, pressure, or density measurement devices:

   i. damage to or malfunction of temperature devices;

   ii. damage to or malfunction of pressure devices;

   iii. damage to or malfunction of density devices.

c) **Auxiliary Equipment**

   1) pumps;

   2) reservoirs;

   3) hoses and connections;

   4) valves and manifolds;

   5) temperature, pressure, and density devices;

   6) temperature, pressure, and density transmission.

d) **Data Capture and Calculation Equipment**

   1) temperature, pressure, and density data recording;

   2) temperature, pressure, and density data transmission;

   3) temperature, pressure, and density data capture;

   4) manual reading, recording, proofing, and computer entry of data;

   5) data calculation hardware and software;

   6) traceability documents not being current;

   7) traceability documents do not match serial numbers of equipment.

e) **Human Errors**

   1) errors in determining and recording test measure data;

   2) errors in determining and recording temperature and pressure data;

   3) utilization of incorrect test measure data;

   4) errors in data entry and/or calculations;

   5) scale reading errors:

      i. reading with eye level not perpendicular to the scale;

      ii. reading at level other than bottom of meniscus;

      iii. reading before thumping;

      iv. reading with test measure not in level state at perpendicular axes at time of reading;

      v. allowing unclean sight glass to cause an ill-defined meniscus.

Each of the above sources should be carefully examined until the cause of the abnormal measurement is determined.

Annex B
(informative)

Witnessing Guidelines

A witness should know which calibration method (volumetric, gravimetric, or master meter) will be performed. One technician usually performs the calibration in the company of several others who are designated as the witnesses. A witness is usually a representative of an associated company having operational, financial, or other interests in the custody transfer functions at that facility. Company employees from the same or other divisions are often involved, and federal, state, or local government officials will occasionally be present.

The items listed below could be considered part of the witnessing process. There are no requirements for a witness of prover calibrations.

a) **Documentation Review**

   1) Obtain previous calibration certificate if applicable to compare sphere inflation (percent oversized) and durometer, piston, and previous volume.

b) **Test Measure, Weigh Scale, and Instrument Review and Inspection**

   1) Validate the traceability of equipment by checking the calibration dates and the availability of valid calibration certificates and other records.

      i. test measures:

         1) have NIST calibration certificates;

         2) calibration and test measure seal numbers match;

         3) are certified within five years by NIST;

         4) there are no dents that are not documented on calibration certificate;

         5) interior surfaces of all applicable test measures are clean and free of film, grease buildup, or other substances;

         6) affixed anti-swirl plate;

         7) adjustable scales are sealed;

         8) inspect all non-invertible test measures used to ensure the following requirements:

            a) rigid sloping drain line;

            b) drain valve that is “quick acting”;

            c) drain valve(s) with leak detection capability;

            d) test measures are level while filled.

         9) calibration worksheets have the correct can numbers.

      ii. weigh scales/weights:

1) have current weigh scale certifications;

2) have current test weight certifications;

3) verify weigh scale is level;

4) weigh scale verification performed.

iii. thermometers:

1) certified within one-year traceable back to NIST;

2) for glass thermometers, discriminate to at least 0.2 °F;

3) compared against each other and documented;

4) the verification requirement for glass and digital thermometers is 0.1 °F.

iv. pressure gauges:

1) certified within one-year traceable back to NIST;

2) discrimination shall meet 7.5;

3) compared against each other and documented.

c) **Witness Prover and Test Measure Preparation**

1) Prover

i. internal of prover is clean and free of oil;

ii. internal coating of prover is in good condition;

iii. skillets isolating the prover interchange from the prover, if applicable;

iv. sphere inflation (percent oversized) and durometer or piston for present waterdraw compare with previous waterdraw;

v. inspection and maintenance of the detector switches;

vi. calibration liquid conditions (air vented, clean with no aeration, hydrocarbons, or detergents if water is used);

vii. no leaks on prover, waterdraw unit, or at hose connections.

2) Test Measure

i. drain valves on test measures not being used are open;

ii. all air is purged from system.

3) Weigh Scale

i. verify the scale is level and witness the weigh scale verification.

d) **Witness Prover Calibration Operations**

1) Water is fresh and clean with no aeration.

2) Flow rate is held fairly stable with no stoppage of the ball.

3) Calibration unit interchange integrity is checked where applicable.

4) Block valve integrity is checked where applicable.

5) Filling and general operation of the test measures (waterdraw) or the general operation of the master meter and master prover or the weigh system for gravimetric method.

6) Test measure scale readings and interpolations (waterdraw). Discuss with the technician prior to the calibration which test measure(s) need to be read.

7) The recording of the weight for gravimetric.

8) Test measure water temperature taken at a test measure outlet.

9) Prover water temperature taken as near as possible to a prover while water is flowing to test measures.

10) Pressure reading recorded while water is passing through the solenoid valve.

11) Observe water start/stop as soon as displacer contacts detector switches.

12) Observe test measure scale readings and interpolations (waterdraw).

13) Observe water temperature of each test measure or container.

14) Observe thermometer submerged in water while not in use.

15) Observe prover temperature.

16) Observe test measure drain down time after cessation of main flow (30 seconds for stationary bottom-drain test measures, 10 seconds for inverted test measures).

17) Observe or keep the recording (handwritten) of all the calibration data as log entries.

18) Flow rates vary by at least 25 % for each consecutive run (both unidirectional and bidirectional).

19) Three runs are performed (passes for unidirectional and round trips for bidirectional).

20) In general, witness the resolution of all the operations, processes, and problems encountered.

Annex C
(normative)

Documentation Requirements for Calibration Certificates

Annex C defines the minimum required documentation for all prover calibration certificates. This requirement applies to all three methods: waterdraw (API *MPMS* Chapter 4.9.2), master meter (API *MPMS* Chapter 4.9.3), and gravimetric (API *MPMS* Chapter 4.9.4). Each individual method will have additional unique information to be documented on the prover calibration certificate.

The information below will be reported in the calibration report.

— date of certification;

— unique certificate (report) number;

— owner of the prover;

— operator of the field prover (if different from the owner);

— operational/service location;

— calibration location;

— prover type;

— manufacturer of the prover;

— serial number;

— API calculation method performed (API *MPMS* Ch. 4.9.2, API *MPMS* Ch. 4.9.3, or API *MPMS* Ch. 4.9.4);

— base prover volume (BPV);

— temperature base for BPV;

— pressure base for BPV;

— BPV identifier if the prover has multiple volumes/detectors;

— name, address, company, and signature of person providing certificate;

— designated reference thermometer's, serial number and certification date;

— designated reference pressure indicator's serial number and certification date;

— prover's measurement chamber material of construction;

— coefficient of thermal expansion for the material of construction (G_c, G_a, and G_l, or G_{cm});

— modulus of elasticity (E) for the material of construction;

— prover:

    — inside diameter (ID);

— wall thickness (WT).

Subsequent pages of the package include.

— run data collected for the certification (handwritten or automated);

— calculations to determine the base prover volume (BPV);

— designated reference thermometer certificate;

— working thermometers verification (see 7.4);

— designated reference pressure reference (gauge) certificate;

— working pressure references verification;

— method-specific information.

Annex D
(informative)

U.S. Customary (USC) Unit Conversion to International System (SI) for this Standard

For the U.S. Customary (USC) units presented in this standard, the SI unit equivalents are:

Temperature:

— 0.1 °F (0.05 °C);

— 0.2 °F (0.1 °C);

— 0.01 °F (0.01 °C).

Pressure:

— 1.0 psig (6.9 kPag);

— 20 psig (138 kPag);

— 60 psig (414 kPag).

Volume:

— 500 gallons (1.893 m^3);

— 1000 gallons (3.785 m^3).

Bibliography

[1] API *MPMS* Chapter 4 (all sections), *Proving Systems*

[2] API *MPMS* Chapter 7 (all sections), *Temperature Determination*

[3] API *MPMS* Chapter 21.2, *Electric Liquid Volume Measurement Using Positive Displacement and Turbine Meters*

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