

Manual of Petroleum Measurement Standards Chapter 4—Proving Systems

Section 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

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Foreword

This multi-part publication consolidates and standardizes calibration procedures for displacement and volumetric tank provers used in the metering of petroleum liquids. It provides essential information on the operations involved in obtaining a valid, accurate and acceptable prover volume by different calibration methods. Units of measure in this publication are in the International System (SI) and United States Customary (USC) units consistent with North American industry practices. The parts consist of the following:

- Part 1—*Introduction to the Determination of the Volume of Displacement and Tank Provers*;
- Part 2—*Determination of the Volume of Displacement and Tank Provers by the Waterdraw Method of Calibration*;
- Part 3—*Determination of the Volume of Displacement Provers by the Master Meter Method of Calibration*;
- Part 4—*Determination of the Volume of Displacement and Tank Provers by the Gravimetric Method of Calibration*.

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Introduction

This standard describes the gravimetric method of calibration (GM), which is used to determine the calibrated volume of both displacement and tank provers. All prover volumes shall be determined by calibration and not by calculation.

The GM differs from the waterdraw (volumetric) method found in API *MPMS* Ch. 4.9.2. The main difference between the methods is that a field standard test measure is replaced with a weighing system (weigh scale and container).

A majority of 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 are identical for the waterdraw and GMs. This standard will describe activities that are different from the waterdraw method. Therefore, it will be necessary for the user to reference API *MPMS* Ch. 4.9.1 and API *MPMS* Ch. 4.9.2 to perform all activities necessary for a calibration. Detailed volume calculation procedures for this method are included in Annex A.

Chapter 4—Proving Systems

Section 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

1 Scope

1.1 General

This standard covers the specific procedures, equipment, and calculations required to determine the Base Prover Volume (BPV), of both tank and displacement provers by the gravimetric method of calibration (GM).

1.2 U.S. Customary (USC) and International System (SI) Units

This standard presents both International Systems (SI) and U.S. Customary (USC) units, and may be implemented in either system of units. The presentation of both units is for the convenience of the user, and is not necessarily the exact conversions. The system of units to be used is typically determined by contract, regulatory requirement, the manufacturer, or the user's calibration program.

1.3 National Metrology Institute

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

1.4 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. It is also the duty of the user to comply with all existing federal, state, or local regulations [e.g. the Occupational Safety and Health Administration (OSHA)] that govern the types of activities described in this standard, and to be familiar with all such safety and health regulations.

2 Normative References

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

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

API MPMS Chapter 4 (All Sections), Proving Systems

API MPMS Chapter 5 (All Sections), Metering

API MPMS Chapter 7 (All Sections), Temperature Determination

API MPMS Chapter 9 (All Sections), Density Determination

API MPMS Chapter 11 (All Sections), Physical Properties Data

API MPMS Chapter 12 (All Sections), Calculation of Petroleum Quantities

API MPMS Chapter 13 (All Sections), Statistical Aspects of Measuring and Sampling

API MPMS Chapter 14, Part 6—*Continuous Density Measurement*

API MPMS Chapter 15, *Guidelines for Use of the International System of Units (SI) in the Petroleum and Allied Industries*

ASTM E617-97: 2008 ¹, *Standard Specification for Laboratory Weights And Precision Mass Standards*

EPA ² *Secondary Drinking Water Regulations*

NIST Special Publication 250-72 ³, *Liquid Volume Calibration Service*

OIML International Recommendation R 111 ⁴, *Weights of classes E₁, E₂, F₁, F₂, M₁, M₁₋₂, M₂, M₂₋₃ and M₃—Part 1: Metrological and technical requirements*

3 Terms and Definitions

For the purposes of this document, the following definitions apply. The publications in Section 2 may be referenced for additional definitions relating to the calibration of displacement and tank provers.

3.1

aggregate mass

Each certified weight has a nominal value of mass along with an “as left mass” value from its certificate. The nominal value of mass and the “as left mass” of the weight must be summed to determine the aggregate mass of the weight.

3.2

as left mass

The actual value of mass that a weight differs from the nominal value of mass of that weight. Example a 50 kg weight (nominal value) may have an as left mass of 0.001 kg. The aggregate mass of the weight would be 50.001 kg.

3.3

calibration water

The actual water used in the calibration process. The water used cannot be nontreated water defined in 3.8.

3.4

container

A collection tank that fits on a weigh scale (balance, load cell, weighing device, etc.) and contains either all or part of the fluid from the prover during calibration for weighing.

3.5

direct traceability

Documentation demonstrating that the standard in question (weight, pressure gauge, thermometer) was tested by a National Metrology Institute.

3.6

expected mass

The estimated mass to be weighed from the volume dispensed by the prover.

EXAMPLE For a prover with a nominal volume of 20 gal, the expected (estimated) mass of water would be 75.659 kg.

¹ ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

² U.S. Environmental Protection Agency, Ariel Rios Building, 1200 Pennsylvania Avenue, Washington, DC 20460, www.epa.gov.

³ National Institute of Standards and Technology, 100 Bureau Drive, Stop 3460, Gaithersburg, Maryland 20899, www.nist.gov.

⁴ International Organization of Legal Metrology, 11 Rue Turgot, Paris, France F-75009, <http://www.oiml.org/>.

3.7

indirect traceability

Documentation demonstrating that the standard in question (weight, pressure gauge, thermometer) was tested by a laboratory with direct traceability to a National Metrology Institute and in compliance with that institute's quality assurance program.

3.8

nontreated water

Water that does not meet the potable or reference water definitions. Nontreated water is not used for gravimetric calibrations.

3.9

potable water

Water from an approved public municipal system that meets the EPA secondary contaminate levels for a maximum total dissolved solids of 500 mg/L (1000 μ S).

3.10

reference water

Water from a distilled, deionized or reverse osmosis source with a maximum conductivity of 50 microsiemens (μ S).

3.11

tare

A term meaning to perform the action to zero the weigh scale. An electronic weigh scale may indicate a mass reading with no mass applied. The weigh scale would then be tared (zeroed) before a weighing. A tare can normally be performed with a significant amount of mass on the weigh scale. The reason to tare with a mass applied would be to obtain a net change in mass.

3.12

target mass (weight)

The predetermined aggregate mass of test weight(s) needed for verification of the weigh scale. The target mass must be within ± 20 % of the total mass.

3.13

total mass

The combined mass of the water to be weighed and the mass of the container. The mass of water to be weighed can be a partial, or the whole prover volume.

4 Prover Preparation

The guidelines or requirements for the preparation of provers for the GM are identical to those found in API *MPMS* Ch. 4.9.1 and API *MPMS* Ch. 4.9.2.

5 Preliminary and General Calibration Procedures

5.1 General

The preliminary and general calibration procedures for provers utilizing the GM are identical to those methods found in API *MPMS* Ch. 4.9.2 except for those procedures described in this section.

5.2 Preliminary Calibration Procedures

5.2.1 General

For displacement type provers, the water representing the prover volume is displaced into a container located on a weigh scale. For open tank provers, the GM may use either the drawing of water from the tank prover into the container or alternatively by filling of the tank prover from the container. The weight of the displaced water is then determined and corrected for the effect of air buoyancy to determine mass.

The mass obtained shall then be divided by the density of the water at the prover conditions of temperature and pressure to obtain the volume of water displaced. Corrections for temperature and pressure of the prover metal shall then be applied to this volume to determine the volume of the prover at reference conditions for any given calibration run. The prover base volume is the average of a set of runs that meet the repeatability criteria.

Because of environmental conditions in the field (wind, rain, snow, etc.) that may affect the weight measurement, the GM is more suitable for calibrations carried out in controlled environments.

5.2.2 Calibration Records

All the involved parties should review the calibration certificate from the previous prover calibration together with all the past maintenance records and calibration history of the prover that is available. Confirm that the identifying numbers on all the calibrated equipment (weights, thermometers, weigh scales, pressure gauges, etc.) to be used in the calibration correspond to their respective up-to-date traceability certificates.

5.2.3 Temperature and Pressure Device Verification

For procedures relating to temperature and pressure device verifications and applicable certificates of traceability refer to API MPMS Ch. 4.9.1.

5.2.4 Temperature and Pressure Readings

For procedures relating to temperature and pressure device readings refer to API MPMS Ch. 4.9.2. The temperature reading for the determination of the water density shall be obtained at the prover as in the waterdraw method. A temperature or pressure reading of the water in the container (or at the weight scale) is not required for a gravimetric calculation.

5.2.5 Gravimetric Calibration Unit (GM Unit)

The equipment used in the GM is the same as the waterdraw method found in API MPMS Ch. 4.9.2 except for the test measure is replaced with a weighing system.

A GM unit consists of a water reservoir, a low-pressure centrifugal pump, associated pipe work, hoses, and maybe a four-way valve. Included on the unit is a solenoid valve assembly, a control panel with detector switch indicator assembly, and a weighing system. The weighing system is normally positioned so that the water can be drained or pumped directly back into a reservoir. Single or multiple solenoid valves may be used, depending upon the piping configuration selected. Two-way or three-way type solenoid valves may be used as long as all valves can be verified for leakage. A centrifugal pump circulates water from the reservoir through the prover. The water is then returned either into the container and/or back into the reservoir.

5.2.6 Weighing System

5.2.6.1 General

A weighing system consists of weigh scale(s), test weight(s), and a container(s) to hold the calibration water.

5.2.6.2 Weigh Scale

A weigh scale shall be employed to determine the mass of the water displaced between volume detector sensors of the prover undergoing calibration. The weigh scale shall provide a minimum precision (repeatability) of $\pm 0.0025\%$, or ± 1 part in 40,000, and shall be internally temperature compensated for an ambient temperature range of $-10\text{ }^{\circ}\text{C}$, to $+40\text{ }^{\circ}\text{C}$ ($14\text{ }^{\circ}\text{F}$ to $104\text{ }^{\circ}\text{F}$). The above stated precision provides a four-to-one ratio of higher accuracy, to that of the prover undergoing calibration, of $\pm 0.01\%$, or ± 1 part in 10,000.

The weigh scale shall be originally certified (calibrated) and supplied with indirect traceability to a national metrology institute. A documented performance verification (per manufacturer's recommendations) and recertification of the weigh scale(s) shall be conducted every three years. Recertifications must be performed by scale service company with national accreditation such as National Voluntary Laboratory Accreditation Program (NVLAP) or The American Association for Laboratory Accreditation (A2LA).

5.2.6.3 Test Weights

Test laboratory weights and precision mass standards, in conformance with ASTM E617, or OIML International Recommendation R 111-1, shall be employed to verify/calibrate weigh scales used for gravimetric calibration of provers.

Test weights shall be certified initially and recertified every three years with direct or indirect traceability to a national metrology institute. A calibration certificate shall be issued by the calibration party, and maintained by user. The following minimum information shall be included on the calibration report:

- name and address of the calibrating party;
- identification and serial number of the calibrated weight;
- nominal mass value;
- as found, and as left mass of the weight;
- a statement of the estimated uncertainty of the weight;
- report number;
- national metrology institute certificate number;
- environmental conditions and procedures used;
- NVLAP or other type of national accreditation logo;
- information on the traceable standards used; and
- owner/client/contractor name and address.

Test weight(s) shall be ASTM E617 Class 0, Class 1, Class 2, Class 3, Class 4 or equivalent and shall not exceed a metric weight of 500 kg, or equivalent avoirdupois denominations [e.g. ASTM Class 4 "nominal" tolerances are one part in 50,000 (0.002 %)].

Multiple weights may be used in lieu of single weights. The plus or minus value "as left" mass for each weight shall be accumulated to establish an aggregate mass for each verification/calibration procedure. Test weight materials of construction shall be corrosion resistant, and practically nonmagnetic. An inspection of the weights shall be conducted to substantiate mass integrity of each weight (no loss or gain in mass). Any event resulting in possible change in the mass of a weight shall be reason for recertification prior to the three-year requirement.

5.2.6.4 Container

The container is any vessel that meets these requirements:

- must center the contained mass of water to the weigh scale platform,
- material of construction and the condition of the container must not affect the conductivity or density of the water,
- container mass plus expected mass of fluid must not exceed the capacity of the weigh scale, and
- minimize evaporation of water in low humidity environments and/or higher atmospheric temperatures.

5.2.6.5 Weigh Scale Verification/Calibration

Weigh scales used in the GM shall be verified or calibrated before each prover calibration procedure, or series thereof, conducted in a 24-hour period. Typically, a calibration is performed at one or two points over the scale's range, while verifications must be performed at each target mass. For each weigh scale verification and/or calibration procedure, the weigh scale(s) must adhere to the conditions below.

- Must be powered (turned on) for a sufficient amount of time to allow the electronics to stabilize (see manufacturers recommendations).
- Must be protected from wind drafts, rain, snow, etc., which could affect the weight measurement during the procedure.
- Must be equipped with a tare function, to tare out the weight of the container, prior to each calibration pass or container fill.
- Mounted on a level, stable, vibration free surface. If the weigh scale is not equipped with a level indicator, an appropriate level shall be used to verify that the weigh scale pan is horizontal.
- Must be level when empty, and when reading the total mass weight.
- Must be verified (calibrated) with test weight(s), as described in 5.2.6.3.
- Must be verified with a mass of test weights within $\pm 20\%$ of the total mass. The total mass is the expected mass of the volume (partial or whole) dispensed from the prover plus the mass of the empty container.
- The mass indication (reading) of the weigh scale during verification, calibration, or weighing must be within the readability of the weigh scale and 0.005 % of the total mass.
- Linearity shall not be relied upon to provide the stated accuracy for multiple weigh points at various points within the capacity of the weigh scale. The weigh scale should be verified at each weigh point (total mass for each prover volume).

Reverification (or calibration) of the scale(s) is necessary due to:

- weigh scale relocation,
- weigh scale out of level during the procedure,
- change in volume (total mass) to be weighed by $\pm 20\%$,
- over-ranging the weigh scale,
- loss of power to weigh scale.

NOTE Refer to the weigh scale manufactures detailed instructions and recommendations for calibrations.

5.2.6.6 Draining of the Container

A container may be drained in any manner that does not effect the level or position of the weigh scale. Pumping the water from the container is allowed, but the pump or discharge hose must be removed before taring or refilling. The container may retain residual water after draining, provided that the weigh scale is tared before the next fill sequence. Note that the amount of residual water should be minimal and must not be enough to make the next total mass outside of the target mass.

5.2.6.7 Taring/Zeroing the Weigh Scale

A weigh scale may indicate a mass reading with no mass applied. The weigh scale would then be tared (zeroed) before a weighing of water. A tare can also be performed with a significant amount of mass on the weigh scale. The reason to tare with a mass applied would be to obtain a net change in mass.

The weigh scale should be tared/zeroed before:

- verification,
- calibration,
- placing the container on the weigh scale,
- each weighing sequence during the calibration.

5.2.7 Water Quality

5.2.7.1 General

Ideally, for gravimetric calibrations, distilled or deionized water should be used. Water density is very important in gravimetric calibrations. Dirty water, heavily aerated water, hydrocarbon contaminated water, salt water, or any water of inferior quality, cannot be used (see Section 3 for water definitions). The density of the distilled or deionized water can be found in numerous tables. The algorithms developed by Patterson and Morris are currently used in petroleum industry standards.

For purposes of this standard, the density of water that has been defined as “reference water” can be obtained from the Patterson Morris algorithms in API MPMS Ch. 11.4.1. The “reference water” must be from a distilled, deionized or reverse osmosis source with a maximum conductivity of 50 μS .

Potable water from an approved public water (potable) supply may be used as calibration water in this procedure if “reference water” is unavailable (see definition in Section 3). If the density of the potable water exceeds 50 μS , the

water density can be estimated for this procedure from its conductivity reading. The water conductivity should be determined at the completion of each run. Those conductivity readings used for each run must not differ by more than 200 μS and must not exceed 1000 μS during the prover calibration procedure. To determine the density of the potable water, see Equation (6) through Equation (11) in Annex A.

NOTE The use of potable water instead of “reference water” may increase the uncertainty of a gravimetric calibration.

5.2.7.2 Water Conductivity Measurement

Water conducts electricity to some degree. Adding impurities that dissolve in the water such as salts increases its conductivity. Therefore, conductivity measurements can be used to correlate dissolved solids in solutions. Correlations improve as solids concentration and solids types are limited or similar.

Conductivity meters are common and typically simple instruments to operate. A meter for this standard:

- must be temperature compensated,
- indicate in the international unit of measure for conductivity, microsiemen (μS),
- indicate in increments of one for solutions below 75 μS , and
- indicate in increments of 10 or less for solutions above 75 μS .

Conductivity meter/measurement recommendations:

- use commercially-available standard and traceable solutions for calibration/verification,
- ensure no bubbles or particulate matter is in test solution,
- ensure meter (probe or cell) is properly immersed in test solution,
- ensure no salts or particulate matter is allowed to build up on probes or cells,
- rinse meter with deionized or distilled water before storage and any test sequence,
- follow manufactures recommendations for storage and calibration.

5.2.8 Air

Air must be vented from all high points in the system before beginning the calibration. The prover calibration depends upon a true hydraulic displacement, which is only possible in an air-free system. If air is found during a calibration pass, that pass is invalid and must not be used in the volume determinations. If air is found after the last calibration pass the complete calibration sequence is invalid and must be repeated.

5.2.9 Flow Rates During Calibration of Displacement Provers

Calibration flow rates should be chosen so that the displacer will have a steady continuous movement throughout the calibration pass. During all calibration passes it is desirable to keep the displacer moving smoothly at a constant flow rate. If the flow must be stopped at any time (e.g. waiting to empty container), the displacer should be stopped and restarted smoothly and quickly.

The minimum flow rate is experienced when the water flow is passing only through the solenoid valve. If the displacer shudders or moves erratically at this time, it may be a sign:

- that the displacer is not lubricated sufficiently,
- the displacer is sized incorrectly,
- that the solenoid valve opening is too small,
- that there is air in the system,
- that the water pressure is improperly changing.

The calibration shall be performed at flow rates such that the container can be filled without surging, overflowing, evaporation, or splashing water out of the top. Any splashing, overflowing or other loss of water from the container prior to the recording of the mass indication will render that calibration pass invalid.

For leak detection and reproducibility purposes, the flow rate for displacement provers shall be changed between successive calibration runs by 25 % or more.

The flow rate can be determined by one of two methods:

- a flow meter, or
- timing the entire calibration pass/run $[(\text{total volume}/\text{time}) = \text{flow rate}]$.

Regardless of the method used, a change of 25 % or more to the flow rate applies to the entire calibration pass/run and not to just a portion of the pass/run.

5.2.10 Number, Continuity and Sequence of Calibration Runs

A minimum of three consecutive calibration runs are required for a successful calibration of displacement provers.

Two consecutive calibration runs are required for a successful tank prover calibration. If the tank calibration scale is moved, then a third calibration run is required.

Any measured run is part of the consecutive chain. However, in the case of mishaps, such as the overflowing of a container, forgetting to close a drain valve, opening the wrong valve, missing a temperature, etc., the displacer may be returned to its previous starting position, and that particular pass or run started over.

If a displacement prover has multiple volumes, each volume shall be considered to be a stand-alone and independent prover volume. Each of these prover volumes shall be calibrated by a separate and independent calibration. Each calibration shall meet the same criteria as described above.

5.2.11 Calculations and Repeatability

Detailed volume calculation procedures are included in Annex A of this standard. A majority of the calculations come from following editions of API *MPMS* Ch. 11.4.1, API *MPMS* Ch. 12.2.4, and API *MPMS* Ch. 14.6. Any equation referenced in Table A.1 will be superseded by calculations in any revised editions of these standards or new API *MPMS* Ch. 12 standards addressing gravimetric calibrations.

Repeatability between the results of successive prover volumes (passes and runs) at standard conditions must be calculated. For complete details on the determination of repeatability, refer to the API *MPMS* Ch. 12.2.4 or Equation (A.24) of this document.

5.2.12 Calibration Certificate Package

All observed data shall be hand written in ink. All the observed data shall be proof read against the computer input-data before signing any documents. In case of discrepancies or errors discovered at a later date, the hand written observed data shall be used to correct the final volume. See Annex E for an example of gravimetric calibration datasheets.

A calibration certificate package for the GM shall include the applicable items listed in API MPMS Ch. 4.9.2 and these additional items:

- manufacturer, model, and serial number of weigh scale,
- weight certifications (see 5.2.6.3),
- documentation of weigh scale verification (see Annex F),
- certification for calibration water used to verify conductivity meter.

5.3 General Calibration Procedures

A majority of the activities necessary to conduct calibration runs, and record all the required data are identical for the “waterdraw” and “gravimetric” methods. The difference is that the field test measure is replaced with a weighing system. This section will briefly describe procedures for operation of the weighing system.

NOTE API MPMS Ch. 4.9.2 should be reviewed for detailed calibration information related to each type of prover and the issues of each type.

The weigh scale must be verified or calibrated before each procedure or series of procedures of provers of the same volume in a 24-hour period. Section 5.2.6.5 has additional details related to verification or calibration. The weigh scale must be verified prior to the prover calibration even if it has just been recently calibrated. Either procedure should not be performed until the weigh scale electronics have stabilized (reference manufacturers recommendations). Failure to allow the weigh scale to stabilize will result in incorrect readings or nonrepeatable indications.

The target mass for verification must be within $\pm 20\%$ of the total mass as defined. The verification indication (reading) must be within 0.005% of aggregate mass of the total number of weights used to reach the target weight. A complete verification is two consecutive indications (readings) within tolerance at the aggregate mass and at zero mass. An example for a 20-gal prover would be:

expected mass = 75.659 kg

container mass = 18 kg

total mass = 93.6591 kg

target mass = 75 kg to 112 kg

aggregate mass of four 22 kg weights is 90.724 kg

verification reading would be ± 4.5 g of 90.724 kg

Once the verification procedure is complete, then the weigh scale should be tared. If only one container will be used per weigh scale, then the weigh scale should be tared with the container centered on the weigh scale platform. If multiple containers will be used per weigh scale, then an empty and total mass indication must be recorded per container to obtain the net mass of each container. Although it is not necessary to wet the container (fill with water) prior to a calibration sequence, the weigh scale must be level when the container is full of water.