

Manual of Petroleum Measurement Standards Chapter 4—Proving Systems

Section 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

FIRST EDITION, DECEMBER 2005

REAFFIRMED, JULY 2015



AMERICAN PETROLEUM INSTITUTE

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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. Part 1 is the introduction and contains those aspects that are generic to the various methods of calibration, including waterdraw (WD), master meter (MM) and gravimetric (GM). Each subsequent part is intended to be used in conjunction with Part 1 for the particular calibration procedure described. This section consists of the following four parts:

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 Provers by the Gravimetric Method of Calibration”

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

CONTENTS

	Page
1.0 INTRODUCTION	1
1.1 U.S. Customary And Metric (Si) Units	1
1.2 National Weights and Measures Agencies	1
1.3 Safety Considerations	1
2.0 SCOPE	1
3.0 REFERENCE PUBLICATIONS	1
4.0 TERMS AND APPLICATIONS	2
4.1 TERMS	2
4.2 APPLICATIONS	2
5.0 PROVER CLEANING AND PREPARATION	3
5.1 Isolation of the Prover	3
5.2 Initial Prover Preparation.	3
5.3 Purging and Cleaning of the Prover	4
5.4 Sphere Displacer Inspection, Sizing and Preparation	4
5.5 Water Filling, Venting and Circulation of Pipe Provers	7
6.0 PRELIMINARY AND GENERAL CALIBRATION PROCEDURES	7
6.1 General Calibration Discussion.	7
6.2 Displacement Type Unidirectional Provers with Free Displacers	18
6.3 Displacement Type Bi-directional Provers with Free Displacers.	19
6.4 Displacement Type Meter Provers with Captive Displacers	21
6.5 Atmospheric Tank Provers	22
7.0 CALIBRATION PROCEDURES BY TYPE OF PROVER	26
7.1 Calibration Preparation	26
7.2 Displacement Type Unidirectional Provers with Free Displacers	27
7.3 Displacement Type Bi-directional Provers with Free Displacers.	28
7.4 Displacement Type Meter Provers with Captive Displacers	30
7.5 Atmospheric Tank Provers	32
8.0 TROUBLESHOOTING CALIBRATION PROBLEMS.	35
8.1 Evaluation of Calibration Results	35
8.2 Leaks	36
8.3 Prover Detector Switches	36
8.4 Sphere Interchanges.	36
8.5 Four-Way Valves	36
8.6 Displacers.	37
8.7 Drains and Vents	38
8.8 Temperature and Pressure	38
8.9 Pumps, Hoses and Connections.	39
8.10 Detector Switches, Solenoids and Logic Circuits	39
8.11 Field Standard Test Measures.	39
8.12 Piping and Manifolds	39
8.13 Water Quality	40

CONTENTS

	Page
8.14 Air and Entrained Gas	40
8.15 Prover Conditions and Coatings.	40
APPENDIX A (INFORMATIVE) UNCERTAINTIES IN METER PROVER	
CALIBRATIONS	41
APPENDIX B (NORMATIVE) EFFECTS OF TEMPERATURE CHANGES ON THE	
INTERFACE INVENTORY.	49
APPENDIX C (INFORMATIVE) EXAMPLES OF WATERDRAW DATA SHEETS .	53
APPENDIX D (INFORMATIVE) FIELD STANDARD TEST MEASURES	75
Figures	
A.1 Uncertainty Analysis: Detector Switch Actuation Point with	
Respect to the Forward Movement of the Prover Sphere	42
1 Schematic Drawing of a Typical Layout for a Waterdraw Calibration	
of a Displacement Type Unidirectional Prover with a Free Displacer	
using Top-filling Test Measures	83
2A Schematic Drawing of a Typical Layout for a Waterdraw Calibration	
of a Displacement Type Bi-directional Prover with a Free Piston	
Displacer and Check Valves in the Manifold using Top-filling Test Measures. . .	84
2B Schematic Drawing of a Typical Layout for a Waterdraw Calibration	
of a Displacement Type Bi-directional Prover with a Free Sphere	
Displacer using Top-filling Test Measures.	85
3A Schematic Drawing of a Typical Layout for a Waterdraw Calibration	
of the Downstream Volume of a Displacement Prover with a Captive	
Displacer and External Detectors using Top-filling Test Measures.	86
3B Schematic Drawing of a Typical Layout for a Waterdraw Calibration	
of the Upstream Volume of a Displacement Prover with a Captive	
Displacer and External Detectors using Top-filling Test Measures.	87
3C Schematic Drawing of a Typical Layout for a Waterdraw Calibration	
of a Displacement Prover with Equal Size Diameter Shafts on Both Sides	
of a Captive Displacer and External Detectors using Top-filling Test Measures .	88
4A Schematic Drawing of a Typical Layout for a Waterdraw Calibration of a	
Volumetric Tank Prover with a Bottom Weir using Top-filling Test Measures . .	89
4B Schematic Drawing of a Typical Layout for a Waterdraw Calibration	
of a Volumetric Tank Prover with a Dry Bottom using the Water-fill	
Method and using Top-filling Test Measures.	90
4C Schematic Drawing of a Typical Layout for a Waterdraw Calibration of a	
Volumetric Tank Prover with a Wet Bottom using Top-filling Test Measures . . .	91
5 Alternate Method—Schematic Drawing of a Typical Layout for a Waterdraw	
Calibration of a Proving System using Bottom-filling Test Measures	92

CONTENTS

	Page
Tables	
1 Sphere Ovality Verification	5
2 Sphere Sealing Width Relationships.	7
A-1 Detector Switch, Sphere and Pipe Diameter Uncertainty	44
A-2 Uncertainty Due to Test Measure Combination	45
A-3 Estimated Uncertainty of Prover Calibration Runs (at the 95% confidence level)	46
A-4 Assumed Values from A.1, A.2 and A.3 for illustration purposes only	47
B-1 Temperature Difference in Interface Inventory	49
B-2	50
D-1 Test Measure Discharge Times Based on Volume and Drain Size	76
D-2 Normal and High Sensitivity Test Measures Interpolation of Volumes between the Lowest Scale Lines on Field Standard Test Measures	77
D-3 Example of Test Measures Available on Waterdraw Unit	78

Chapter 4—Proving Systems

Section 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

1.0 Introduction

All prover volumes used to calibrate meters shall be determined by calibration and not by theoretical calculation. Volumetric provers have an exact reference volume, which has been 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. This standard describes only the waterdraw method of calibration, which is used to accurately determine the calibrated volume of both displacement and tank provers.

1.1 U.S. CUSTOMARY AND METRIC (SI) UNITS

This standard presents both International System (SI) and U.S. Customary (USC) units, and may be implemented in either system of units. The system of units to be used is typically determined by contract, regulatory requirement, the manufacturer, or the user's calibration program. Once a system of units is chosen for a given application, it is not the intent of this standard to allow the arbitrary changing of units within this standard.

1.2 NATIONAL WEIGHTS AND MEASURES AGENCIES

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

1.3 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 (for example, the Occupational Safety and Health Administration) that govern the types of activities described in this standard, and to be familiar with all such safety and health regulations.

2.0 Scope

This standard 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, by the Waterdraw Method of Calibration.

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.

Detailed calculation procedures are not included in this standard. For complete details of calculations applicable to this standard, refer to the latest edition of the *API Manual of Petroleum Measurement Standards*, Chapter 12, Section 2, Part 4, "Calculation of Prover Volumes by the Waterdraw Method."

3.0 Reference Publications

Publications that provided background information, and are a source of reference material on subjects related to waterdraw calibration include the following:

American Petroleum Institute

Manual of Petroleum Measurement Standards (MPMS)

- | | |
|-----------|-----------------------------|
| Chapter 1 | "Vocabulary" |
| Chapter 4 | "Proving Systems" |
| Chapter 5 | "Metering" |
| Chapter 7 | "Temperature Determination" |

Chapter 11	“Physical Properties Data”
Chapter 12	“Calculation of Petroleum Quantities”
Chapter 13	“Statistical Aspects of Measuring and Sampling
Chapter 15	“Guidelines for Use of the International System of Units (SI) in the Petroleum and Allied Industries”

NIST¹

Handbook 105	<i>Specifications and Tolerances for Reference Standards and Field Standard Weights and Measures</i>
Part 3	<i>Specifications and Tolerances for Graduated Neck-Type Volumetric Field Standards</i>
Part 7	<i>Small Volume Provers</i>
Handbook 44	<i>Specifications, Tolerances and Other Technical Requirements for Weighing and Measuring Devices</i>

4.0 Terms And Applications

There are no definitions unique to this document. However, the publications selected in section 3.0 may be referenced for definitions relating to the calibration of displacement and tank provers by the waterdraw method. Terms and symbols described below are acceptable and in common use for the calibration of meter provers.

4.1 TERMS

4.1.1 cessation of main flow: The moment when the full discharging water stream “breaks” and becomes a small trickle during the draining of a field standard test measure.

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

4.1.3 drain time: A fixed time period for completing the draining of a field standard test measure that is calibrated on a “to deliver” basis, as described on the Report of Calibration by the calibrating agency. The draining period starts at the cessation of main flow, and has the same duration as the draining time established when the test measure was calibrated.

4.1.4 field standard test measure: A vessel (usually of stainless steel) fabricated to meet a vigorous design criteria and specification, that is used as the basic standard of volume in the waterdraw calibration of volumetric provers. After calibration by NIST or another appropriate national metrology institute the test measure has a precise volume that is used to calculate the base volume of the prover under test.

4.1.5 “to contain” volume: A method of characterization of a field standard test measure, that determines its volume, at reference temperature, when it is filled from a clean, dry, empty, condition. This volume is not utilized in the waterdraw calibration of provers.

4.1.6 “to deliver” volume: A method of characterization of a field standard test measure, that determines its volume, at reference temperature, when it is emptied from its full condition, and drained in accordance with the prescribed draining time. This volume is utilized in the waterdraw calibration of provers.

4.1.7 waterdraw: A method of calibrating a meter prover by displacing water from the prover into field standard test measures.

4.2 APPLICATIONS

The waterdraw method of prover calibration is based on the drawing of water from a displacement prover into field standard test measures. For open tank provers, the waterdraw method may use either the drawing of water from the tank prover into the field standard test measures or alternatively by filling of the tank prover from the test measures. In all cases an up to date volume certification of each field standard test measure to be used in the calibration, with an acceptable calibrated volume uncertainty, must be provided and be traceable to NIST or other appropriate national metrology institutes.

¹National Institute of Standards and Technology, 1655 N Ft. Myer Drive, Suite 700, Arlington, Virginia, 22209. www.nist.gov

5.0 Prover Cleaning And Preparation

5.1 ISOLATION OF THE PROVER

The prover and its auxiliary piping shall be isolated from all operating systems by either physical isolation with blinds, blind flanges, blanks, spectacles or double block and bleed valves to separate it from the upstream and downstream operating line pressures and products. A complete visual inspection should be made of the entire prover system to assure that the system is properly isolated.

5.2 INITIAL PROVER PREPARATION

New or repaired provers are generally hydrostatically tested prior to placing into service. When a hydrostatic test is required, it shall be conducted prior to the waterdraw calibration. This ensures that the calibrated volume will not be altered by permanent pipe expansion, subsequent tightening of flanges, etc. Piston provers shall be waterdrawn using the same piston design and seals, both material and style, that are utilized in the prover's normal meter proving operation. Substitution of spheres for the piston during calibration shall not be allowed.

Connections to pipe work or flexible hoses are required for water circulation through the prover. These are typically 2 in. threaded connections, which should be as close to the calibrated section as practical. (If vents and drains are being considered for waterdraw connections, their location should ensure that all the water used in the calibration will be circulated through the entire proving system. This is necessary to maintain constant temperature in the calibration water.) Adequate water flow is required to launch the displacer in a pipe prover.

High point vent valves should be inspected. If damaged, defective or leaking they should be repaired or replaced prior to the calibration. Vent valves, in good working order, are necessary for all prover calibrations, to ensure that all air or vapor has been vented from the prover prior to the start of each calibration pass.

Before a prover calibration, all relief valves should be removed, checked for leakage, repaired and re-calibrated as necessary. If in place during the prover calibration then the relief valves should be isolated. If not isolated they must be disconnected from the drain system and regular visual checks for any leakage shall be made.

Drain valves, either on the prover itself, or in manifolds and pipe-work connected to the prover but not isolated from it, must all be inspected for leakage and either sealed off or left uncoupled to enable a visual determination of any leakage during the calibration runs.

Calibration of a prover with the sphere launching interchange or four-way valve isolated does not verify the integrity of operation of the complete proving system. Rather, it simply calibrates the volume contained in a pipe between two switches, which may or may not be acceptable to all the parties concerned.

Depending upon the type of prover to be calibrated the following operations should be performed:

- On a bi-directional prover if its four-way valve is to be used in the calibration process, it shall be checked for condition, smoothness of operation, verify that the seals are holding and ascertain that the valve is leak free. A final check should be made after the prover has been cleaned.
- On a unidirectional prover, if its interchange is to be used in the calibration process, it shall be verified that it is operating correctly, sealing fully, and is leak free. A final check should be made after the prover has been cleaned.
- On provers with captive displacers, a seal leak verification test should be performed. Replace any seals as necessary. Make sure all waterdraw programs and or control boards are present, installed, and working correctly. Any valves or valve systems located internally in the piston, in the prover body itself or in any of the associated pipe-work should be verified and tested. Consult the manufacturer's recommendations for all specifications, leak testing procedures and calibration procedures.
- In piston provers, check the condition of the piston seals and any signs of corrosion on the metal piston itself. Repair or replace as required. Verify the integrity of any valve in the body of the piston. In a free displacer piston prover, check the condition of the piston to ensure that there are no cracks, excessive wear on the wear rings, or other physical changes to the piston that would affect the waterdraw calibration or would cause damage to the prover coating. Free piston displacer seal outer diameters are typically 3 – 5% greater than the pipe inside diameter, and it is recommended that they be no less than 2% oversize.
- On atmospheric tank type provers, block off the vapor recovery system. For wet bottom types make sure there is a hose connection below the "zero" mark. For dry bottom types the connection should be on the downstream side of the block valve.

While the tank prover is full of water, verify that it is level in two axes of a horizontal plane, before beginning the calibration.

Check all prover detector switches to make sure they are in good operating condition. Mechanical detectors may need to be dismantled, cleaned, inspected, repaired and re-assembled as part of the normal preparation for the calibration of a prover. In some cases it may be advantageous to completely replace the detector switches prior to a calibration. As a guide, do all that is necessary to ensure that the detector switches are in good working condition prior to the prover calibration.

5.3 PURGING AND CLEANING OF THE PROVER

Provers in batched crude oil service should be purged with the least viscous available crude unless there is on-site availability of other light hydrocarbon products that can be used. Regardless of service the prover and associated piping shall be cleaned by the best means available and flushed with water until free of all traces of hydrocarbon liquids and solids. Valves may need to be operated to ensure that no hydrocarbon remains. The most widely used method is running the prover displacer back and forth during the water-flush to scrub the walls. Another method, used in crude oil service is to use a hot oil truck to circulate hot water through the prover while pushing the displacer back and forth. When available, steam cleaning is a method for removing wax, paraffin, etc. Pull-through foam pipeline pigs can also be used as an alternative or an additional method of cleaning the interior of pipe provers. Caution should be taken to prevent damage to the internal coating during the cleaning process.

While a detergent can be effective in cleaning a prover, all traces of it must be removed prior to the calibration to prevent foaming. This can sometimes be very difficult to achieve. Therefore, the use of detergents is discouraged except in extreme cases. If it is decided that a detergent has to be used, only a non-suds type should be considered. Even then, it may take a great amount of water to fully remove all traces of the detergent. Nonetheless, all traces of the presence of any detergent must be totally removed before beginning the waterdraw calibration.

LPG pipe provers are best cleaned by filling with water and moving the displacer back and forth to scrub the walls. It is recommended that the prover be drained, refilled and then allowed to stand overnight. The prover is then drained and flushed with clean water. Experience has demonstrated that this procedure eliminates LPG vapors from the piping that can become entrained in the water during the calibration.

After cleaning and while the prover is open, check the condition of the internal surfaces of the prover particularly the condition of the coating. Visual, or mechanical inspection, of the surface areas for any signs of damage, flaking, or missing coating, shall all be carefully examined. Any observations of irregularities in the quality of the internal condition of the prover or any other internal damage shall be carefully assessed and a determination made on its effect on continuing the calibration.

5.4 SPHERE DISPLACER INSPECTION, SIZING AND PREPARATION

Prior to inspection the prover sphere has to be removed from the prover. In order to remove the sphere displacer, send it to the appropriate end chamber if the prover is bi-directional, or to the sphere handling interchange if the prover is unidirectional. Then drain the prover and remove the access cover. Provided the sphere is in place it can be removed either by hand or mechanical means depending upon its size.

Sometimes it will be found that the sphere has not in fact arrived in the chamber but is further back in the prover barrel. If this happens only one procedure is permissible: replace the cover securely, refill the prover, and start again. Under no circumstances shall any attempt be made to force the displacer out with compressed air or gas.

Once the prover sphere has been removed, check the condition to make sure it does not have deep cuts, rips, extreme pitting, holes, flat spots, soft spots, or overall poor condition that may cause leaks or loss of seal. After careful inspection, a decision on its suitability for further use should be made.

The durometer (hardness) and composition of the sphere should be considered as part of prover design. Different hardness and materials can have an effect on both normal operations and calibration, so these must be considered in the design to accommodate both. Because of the lower lubricity of water and greatly reduced flow rates encountered during waterdraw calibrations, a softer durometer sphere usually has a better performance during calibrations. Harder durometer spheres have a difficult time creating a capillary seal inside a prover with anything less than excellent interior coating and round pipe. Conversely, caution should be taken to ensure that the durometer of the sphere is not too soft, otherwise it might have a hard time compressing the spring on the detector switch probe.

Verify the ovality or roundness of the sphere by determining its circumference around two separate axes perpendicular to each other. A circumference variation in the sphere, that is the difference in length around these two perpendicular axes of more than one percent of the nominal circumference, is considered out-of-round. Measuring the sphere, first around its equator, and then around its polar axis usually across the two valve holes, and comparing the difference between the two measurements according to Table 1 will verify sphere roundness. Manufacturing tolerances for new spheres may be up to 1.5%.

Examples of Sphere Ovality Verification:

A 6 in. sphere that is considered to be round, with a nominal diameter of 6.065 in. would be expected to have a diameter variation no greater than $\frac{1}{16}$ in. and a circumference variation no greater than $\frac{3}{16}$ in. Alternatively, a 30 in. sphere with a nominal diameter of 29.250 in. would be expected to have a diameter variation no greater than $\frac{9}{32}$ in. and a circumference variation no greater than $\frac{29}{32}$ in. The comparison measurements in all cases shall be taken around two perpendicular axes of the sphere.

Table 1—Sphere Ovality Verification

Standard Wall Prover Pipe ID (Inches)	Maximum Diameter Variation (Inches)	Maximum Circumference Variation (Inches)
6.065	$\frac{1}{16}$	$\frac{3}{16}$
7.981	$\frac{3}{32}$	$\frac{1}{4}$
10.020	$\frac{3}{32}$	$\frac{5}{16}$
12.000	$\frac{1}{8}$	$\frac{3}{8}$
13.250	$\frac{1}{8}$	$\frac{13}{32}$
15.250	$\frac{5}{32}$	$\frac{15}{32}$
17.250	$\frac{3}{16}$	$\frac{17}{32}$
19.250	$\frac{3}{16}$	$\frac{19}{32}$
21.250	$\frac{7}{32}$	$\frac{21}{32}$
23.250	$\frac{7}{32}$	$\frac{23}{32}$
25.250	$\frac{1}{4}$	$\frac{25}{32}$
27.250	$\frac{9}{32}$	$\frac{27}{32}$
29.250	$\frac{9}{32}$	$\frac{29}{32}$
35.000	$\frac{11}{32}$	$1\text{-}\frac{3}{32}$
41.000	$\frac{13}{32}$	$1\text{-}\frac{9}{32}$
47.000	$\frac{15}{32}$	$1\text{-}\frac{15}{32}$

After the sphere has been inspected and checked, assuming it has passed all the requirements, it can now be prepared for reinstallation by sizing it. The sphere should be sized by an amount greater than the internal diameter of the pipe depending upon circumstances and/or company policies. The magnitude of the sphere over-sizing depends upon the diameter of the pipe, the material of the sphere, the condition of the internal coating and/or the pipe itself. Spheres are generally over-sized in the range of 2 – 5%. Greater over-sizing may be necessary when conditions warrant. However, the need for excessive over-sizing can sometimes be symptomatic of internal problems and irregularities in the prover. The displacer should be sized; large enough to prevent water leakage around the sphere, and small enough to minimize excessive friction and pressure drop.

A liquid (e.g., water, glycol, or a water/glycol mixture) is pumped into the sphere using a small hand pump supplied by the prover manufacturer and the circumference measured until the required size is obtained. For best results a sphere with two inflation valves should be used. Air must be eliminated from the interior of the sphere during the filling by pumping the liquid through the bottom valve of the sphere while displacing the air out through the top valve cavity with the core removed. During final sizing, to ensure that all air is displaced, the sphere is completely filled with liquid. Then the top valve core is reinstalled, and pumping into the sphere is continued until the sphere is sufficiently oversized with the liquid under pressure. The sphere is then vented to the correct size using the top valve. The process of overfilling and venting may need to be repeated several times. Single valve spheres can sometimes be initially filled by removing the valve core and inserting a small tube into the cavity for filling. Once the sphere is essentially full, the procedure would be the same as for a sphere with two valves.

Sizing of the prover sphere is accomplished by one of three general methods, although any other accepted method may be used.

- Set of calipers with openings sufficiently large to pass over the diameter of the appropriate sphere being measured. A ruler or tape measure is used to determine the width of the caliper opening and hence the diameter of the sphere. Measurement around several axes of the sphere can be made and then compared.
- The manufacturer of the prover, per the customer's request, generally can supply specified pre-manufactured sizing rings. Sizes of 2 – 5% over-size are typical, although any size ring can be manufactured, according to the requirements and dimensions of a specific prover. The sizing ring can then be passed over the sphere, around several axes; inflating or deflating the displacer as required to fit, in order to obtain the correct size. *If it is determined that the sphere size must be larger or smaller than the inside diameter of the sizing ring, the sizing ring should be labeled as not suitable for this prover and one of the other sizing methods should be used.*
- Stainless Steel or Plastic Covered Material measuring tapes, preferably $\frac{1}{4}$ in. in width, can go around the circumference of the sphere, along several axes, to obtain a measurement. Comparison around different axes should be made.

Regardless of the method used, all measurements shall be taken across at least two perpendicular diameters or circumferences. The smallest diameter or circumference measured is to be considered the real diameter or circumference of the sphere, so that, whatever percentage inflation is chosen, the sphere will have a minimum diameter or circumference of that amount.

An example of the calculation of the sphere over-sizing is as follows:

Prover Diameter = 16 in.

Wall Thickness = 0.375 in.

I.D. of Prover = $[16 - (2 \times 0.375)] = 15.25$ in.

Prover Circumference = $\pi \times d = 3.141593 \times 15.25 = 47.91$ in.

Sphere Oversize by 3% = $47.91'' \times 1.03 = 49.35''$ (approximately $49\text{-}\frac{3}{8}$ in.)

In the above example the sphere will require its circumference to measure $49\text{-}\frac{3}{8}$ in. after inflation, checked around two axes, to be at three percent over-size in the prover. The lowest axial measurement is taken as the size of the sphere. For example, if the equatorial axis measures $49\text{-}\frac{3}{8}$ in., and the polar axis measures $49\text{-}\frac{5}{8}$ in., then the size of the sphere is considered to be $49\text{-}\frac{3}{8}$ in. or three percent oversize.

Over-sizing the sphere during a calibration is done to prevent water leakage past the displacer during calibration passes. Additional over-sizing may be necessary to compensate for piping irregularities, such as ovality in the pipe, coating problems, and mandrel marks in the 90° bends and the 180° degree returns. However, an excessively over-sized displacer may result in sphere chatter and may cause leakage past the sphere or erratic detector switch activation. Undersized spheres may result in irregular detector switch action and/or leakage past the sphere.

If the prover is constructed with openings in the calibrated section, such as vents, drains, detector holes, or flange separations, etc., that are wider than the surface sealing width of the sphere, a momentary leak path can exist. For example, an 8 in. standard wall pipe prover with a $\frac{1}{2}$ in vent opening will require a prover sphere over-sized by approximately four percent to generate a sealing width sufficient to span the opening width by a comfortable margin, in this example 0.66 in.

Table 2 shows typical relationships between pipe sizes, sphere inflation and surface sealing widths. The purpose of this table is to show the minimum sealing width required to span openings in the measuring section. Sealing width for a different pipe wall thickness and sphere inflation may be calculated by reference to API MPMS Chapter 4 Section 2, Appendix F—Prover Sphere Sizing. Other criteria for sizing the sphere must also be considered.

The displacer shall have one last examination for condition, size and ovality, preferably with an observer (witness) present. Most new detector switches are designed with $\frac{3}{4}$ in. activation rods that pass through the pipe wall. The width of the seal provided by the sphere must be wide enough to cover the void in the pipe wall where mechanical detectors are installed. Before its final installation in the prover, it is suggested that the sphere be covered with a thin coating of a recommended water-resistant lubricant, so that when the displacer is operated at low flow rates during the waterdraw calibration, it will continue to move smoothly through the measuring section. Reinstall the displacer into the prover and close all openings. Record the type of material, durometer (if known), and the size of the displacer on the waterdraw calibration report.

Changes in fluid properties, operating conditions and equipment components may affect the uncertainty of the volume relative to the volume obtained at calibration conditions.

Table 2—Sphere Sealing Width Relationships

Pipe Nominal	Pipe ID	% Inflate	Sealing Width	% Inflate	Sealing Width	% Inflate	Sealing Width	% Inflate	Sealing Width	% Inflate	Sealing Width
6	6.065	2	0.25	2.5	0.31	3	0.37	4	0.50	5	0.64
8	7.981	2	0.33	2.5	0.41	3	0.49	4	0.66	5	0.84
10	10.02	2	0.41	2.5	0.51	3	0.62	4	0.83	5	1.05
12	12.00	2	0.49	3	0.74	4	1.00	5	1.26	6	1.53
14	13.25	2	0.54	3	0.82	4	1.10	5	1.39	6	1.69
16	15.25	2	0.62	3	0.94	4	1.27	5	1.60	6	1.94
18	17.25	2	0.70	3	1.07	4	1.44	5	1.81	6	2.20
20	19.25	2	0.79	3	1.19	4	1.60	5	2.02	6	2.45
22	21.25	2	0.87	3	1.31	4	1.77	5	2.23	6	2.71
24	23.25	2	0.95	3	1.44	4	1.94	5	2.44	6	2.96
26	25.25	3	1.56	4	2.10	5	2.65	6	3.22	7	3.79
28	27.25	3	1.68	4	2.27	5	2.86	6	3.47	7	4.09
30	29.25	3	1.81	4	2.43	5	3.07	6	3.72	7	4.39
36	35.00	3	2.16	4	2.91	5	3.68	6	4.46	7	5.25
42	41.00	3	2.53	4	3.41	5	4.31	6	5.22	7	6.15
48	47.00	3	2.91	4	3.91	5	4.94	6	5.99	7	7.05

Note 1: The inside pipe diameters used in the above table are for illustration only.

5.5 WATER FILLING, VENTING AND CIRCULATION OF PIPE PROVERS

Using a circulating pump start filling the prover with water, which is clean and free from entrained air. Move the sphere or piston through the prover, and vent off any air at all high point vent valves, allowing water to flow from the vents. Air pockets that remain in the prover provide areas that can be compressed during calibration runs. Air has the effect of causing the volume of water displaced to vary, and correspondingly inaccurate or changing prover volumes will result.

Continue passing the sphere or piston around the prover and circulating the water through the prover, until all air is expelled and the temperatures at the prover inlet and outlet are stabilized.

Operators should be aware that on a bi-directional prover, with launch chambers mounted at a 45-degree angle, the vents at the end of the launch chamber are usually lower than the top corners of the launching chambers. In this configuration, it is often extremely difficult to remove all the air without first loosening the top bolts of the blind flanges or releasing slightly the closure doors at the end of the launch chambers. This is usually the only way to vent any pockets of air remaining in the top corners of the launching chambers unless an appropriate vent has been installed to reach these top corners.

6.0 Preliminary and General Calibration Procedures

Changes in fluid properties, operating conditions and equipment components may affect the uncertainty of the volume relative to the volume obtained at calibration conditions.

6.1 GENERAL CALIBRATION DISCUSSION

The base volume of a unidirectional displacement prover is its one-way volume, determined by waterdraw calibration, that is displaced into field standard test measures as the displacer moves from one detector switch (A) to a second detector switch (B), always in the same direction.

The base volume of a bi-directional displacement prover is its round trip volume, determined by waterdraw calibration, that is displaced into field standard test measures as the displacer moves between two detector switches (A and B). A round trip volume consists of the displaced volume in one direction (A to B) plus the following displaced volume in the opposite direction (B to A).

The base volume of a tank prover is its “to deliver” volume, determined by waterdraw calibration, from a liquid level in the upper neck to a liquid level near or at the “zero” position in the lower neck. There are two waterdraw calibration methods or techniques for determining the base volume of a tank prover. Either water is drawn from a full tank prover into various field standard test measures (conventional Waterdraw Method), or water is drawn from various full field standard test measures into the pre-drained tank prover (Water-fill Method).

6.1.1 Calibration Records

All the involved parties (witnesses) should review the Calibration Certificate Package 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 (test measures, thermometers, pressure gauges etc.) to be used in the calibration correspond to their respective reports of calibration. Verify that all the temperature-indicating devices (e.g., thermometers) and pressure-indicating devices (e.g., pressure-gauges) have up-to-date certificates of calibration.

All field standard test measures to be used to calibrate the prover must have up-to-date calibration certificates, which shall be verified. An up-to-date calibration certificate for a test measure is defined in the latest edition of the API MPMS Chapter 4.7, “Field Standard Test Measures.”

In a case where infrequently used test measures, as described in API MPMS Chapter 4.7, are requested to be used in the calibration, this request shall be made before the date of the calibration. All the interested parties shall together determine whether the test measures to be used meet the criteria established for infrequently used test measures. Their findings shall be conclusive and binding, and shall be delivered to the owner/operator of the prover to be calibrated, in writing, before the date of the calibration.

6.1.2 Temperature and Pressure Device Verification

A certified or calibrated thermometer shall be on-site with a certificate of calibration accuracy. The certificate of calibration shall be traceable to NIST or other appropriate national metrology institutes. The certified thermometer shall be used to verify the accuracy of all the other thermometers (working thermometers) used in the calibration procedures. The certified or calibrated thermometer and the working thermometers must agree within $\pm 0.1^\circ\text{F}$ ($\pm 0.05^\circ\text{C}$). Alternatively, working thermometers that have been certified to have been verified at three points (e.g., high, mid and low range points) within one year and a day of the time of the prover calibration by a thermometer that has a calibration traceable to NIST or other appropriate national metrology institutes may also be used providing that all of them agree among themselves within $\pm 0.1^\circ\text{F}$ ($\pm 0.05^\circ\text{C}$).

Electronic temperature measurement devices may be used in the calibration if there is agreement between all the represented parties. If using electronic temperature measurement devices then the requirements laid out in API MPMS Chapter 7, “Temperature Measurement”, shall be followed. As part of the requirement that the device be verified before each calibration, this verification shall be carried out against a calibrated or certified thermometer, accurate to $\pm 0.1^\circ\text{F}$ (0.05°C).

A thorough inspection of all the thermometers to be used shall be made, and care must be taken to observe any signs of mercury separation, or any other defects. Once a set of thermometers has been chosen, an on-site verification of them shall be made to determine that all their readings agree to within 0.1°F (0.05°C) of the calibrated or certified thermometer. This shall be done in a temperature stable water bath that is at the approximate temperature of the water to be used in the calibration of the prover. Any thermometers that are outside of this tolerance shall be rejected as defective. If any electronic thermometric devices are used then all the same requirements as the glass thermometers shall apply. All temperature measuring devices shall be read and recorded to the nearest 0.1°F (0.05°C).

A calibrated dial type pressure gauge, or other acceptable type of pressure device (e.g. digital pressure gauge, pressure transmitter, etc.), accurate to within 1 psi, shall be used for the waterdraw calibration providing that it has a valid certificate of calibration available on-site, which is traceable to NIST or other appropriate national metrology institutes. The definition of a valid certificate of calibration can be found in paragraph 6.7, “Temperature and Pressure Indicators”. If using an analog, dial type, pressure gauge, then before beginning the waterdraw calibration it shall be checked to see that it reads “zero” at atmospheric pressure. If a valid calibration certificate is not available for this pressure gauge, or the “zero” setting requires adjustment then a recalibration of the gauge will be required. Alternatively, another satisfactory pressure gauge shall be obtained that has with it a valid certificate of calibration. If an electronic pressure transmitting and/or digital pressure-indicating device is being used, it shall have a valid certificate of calibration accuracy and be checked for “zero” at atmospheric pressure. If a valid certificate of calibration is not available, or any adjustments to the electronics (e.g. zero, span, gain, range, etc.) have to be made, then a recalibration of the device shall be required. Alternatively, another satisfactory pressure device shall be obtained that has with it a valid certificate of calibration. All pressure measuring devices shall be read and recorded to the nearest one pound per square in. (1 psig).

A selected location performing any of the above temperature or pressure calibrations shall provide all the necessary equipment to carry out these calibrations, including all certificates of calibration accuracy for the equipment and instrumentation used, with full traceability to NIST or other appropriate national metrology institutes.

6.1.3 Temperature Readings

Temperature stability is extremely important in all prover calibrations. Although not always achievable, the intent during any given calibration pass is to keep the test measure water temperatures within 2°F (1°C) of the starting water temperature in the prover.

Water temperature stability and accuracy in bi-directional provers can be compromised by not properly displacing the bulk of the water from calibration pass to calibration pass. If the displacer is moved only a short distance past the second detector switch, and then the direction of the flowing stream is reversed using the four-way valve, the indicated temperature of the prover might not be truly representative of the actual prover temperature. Allowing the displacer to travel all or most of the way to the launching chamber at the end of each pass can enhance temperature stability and accuracy.

Reading errors are a chief source of temperature error. It is essential that all glass stem thermometer readings be taken with the eyes perpendicular to the stem and at the same level as the thermometer medium. Therefore, the thermowell location should be placed in a position where accurate readings can be taken in a comfortable manner. The preferred location for the thermowell would usually be four or five feet above ground level. All temperatures shall be read and recorded to the nearest 0.1°F (0.05°C).

It is recommended that at least two thermometers be used in all calibration passes, as this will expedite taking the prover temperature together with the required test measure temperatures. Careful thought shall be given to the location and installation of the prover thermowell, which is required for the determination of the downstream prover temperature. This temperature shall be taken at a location between the prover outlet detector switch and the inlet to the test measure for each calibration pass, but as close to the prover as practical. This usually means inserting a thermowell between the prover outlet pipe and its first hose connection. In the case of a bi-directional prover where an external four-way valve is used, it is usually necessary to install two thermowells. One thermowell is then used for the downstream temperature of the FORWARD passes, and the other thermowell is used for the downstream temperature of the REVERSE passes. It is extremely important that each thermowell be located in the flowing water stream and in the middle third of the pipe. The pipe diameter shall be small enough to allow the accurate placement of the thermowell. The thermowell probe shall be deep enough to enable the correct immersion of a glass thermometer stem or an electronic thermometer probe. Each thermowell shall also be filled with a suitable heat-conducting medium.

If using electronic temperature measurement devices then the requirements laid out in API MPMS Chapter 7, “Temperature Measurement”, shall be followed. As part of the requirement that the device be verified before each calibration, this verification shall be carried out against a calibrated or certified thermometer, accurate to $\pm 0.1^\circ\text{F}$ (0.05°C).

Temperature stability of the water is the key to a successful calibration. The water used for a waterdraw calibration should have a temperature that lies somewhere between 40°F and 100°F (4 °C and 38 °C), and if possible these limits should be observed. However, water with temperatures outside this range has been used in successful calibrations.

Water temperatures of bottom draining type field standard test measures are usually taken by immersing a fast acting thermometer into the discharging stream, while draining, for a period long enough to stabilize the temperature. The thermometer should have its temperature-sensing bulb contained in a cup case (usually a wood back type), so that its stem is always totally immersed in the discharging stream. The cup case and thermometer shall be held in the stream of water long enough to stabilize during the first third of the discharge from the test measure. When the cup case is lifted out of the stream for reading purposes, the reading should be made quickly to avoid any temperature changes. Steps should be taken to handle only the upper part of the cup case assembly. Holding the reservoir part of the cup case can change the temperature reading. In the case where a portable electronic thermometer (PET) is being used to measure the water discharge temperature, the probe shall be contained in a wood back cup case as with the glass thermometer. This will minimize the effects of ambient temperature on the reading due to voids in the flowing stream. The temperature shall be read with the probe and cup case immersed in the discharging stream and shall not be removed for reading as though it were a glass thermometer.

Temperatures can also be taken by immersion of the thermometer into the main body of water inside the test measure, and agitating the thermometer for an appropriate time to stabilize, withdraw and read. In this case, the temperature reading must be taken after reading the liquid level of the test measure. Exceptions would be:

- Using the test measure to calibrate an atmospheric tank prover by water “filling” the prover
- After filling the test measure prior to transferring the water into a larger test measure for pre-filling

If thermowells are installed within test measures then they may be used to measure water temperatures.



For each pass, displacement provers shall have a water temperature taken at the prover outlet during the displacement of the first third of the water volume. This usually means waiting until the temperature stabilizes, once flow is established into the test measure, since the thermowell is subject to ambient temperature effects between calibration passes (e.g., stopping for a short time, reversing flow, etc.). No temperatures shall be taken while the circulating flow is stopped or when the flow is not filling a test measure. Prover temperatures shall be taken on the downstream side of the displacer and as close as possible to the second detector. This thermowell location will alternate from side to side on bi-directional provers for the “forward” and “back” passes making up a round trip run unless a single thermowell is installed at a common discharge point.

When calibrating a tank prover, the temperature is normally taken when the prover is full of water. This temperature can be taken by immersion of the temperature device into the body of the vessel or by reading thermometers mounted directly into thermowells in the tank prover. The water temperature can also be taken by means of a thermowell installed immediately downstream of the discharge valve. In this case the temperature of the discharging stream of water shall be read at the beginning of the discharge, immediately following the reading of the liquid level on the upper scale, and shall be taken before one-third of the volume has been discharged from the tank prover.

6.1.4 Pressure Readings

Using the calibrated pressure indicator, record the pressure of the water in the prover. This pressure shall be determined at the beginning of the calibration pass when the water is flowing through the solenoid valve line to drain. Pressure on a displacement prover is taken downstream of the second detector for a given pass, while the displacer is approaching the first detector for that same pass and the water is being discharged at a very slow rate through the solenoid valve line back to the reservoir. During the calibration, a minimum back pressure of five psig shall be maintained at the waterdraw calibration unit to ensure the complete packing of all the lines during each calibration pass. All pressures shall be read and recorded to the nearest one pound per square inch (1-psig).

6.1.5 Waterdraw Calibration Unit

When planning waterdraw calibrations, it is critical that the size, volume, and physical location of provers be of prime consideration in determining the optimum waterdraw equipment. Undersized equipment results directly in slower work performance, longer work days and increased meter prover downtime. Proper planning makes for an efficient operation.

A waterdraw calibration unit is generally portable and consists of a water reservoir, a low-pressure centrifugal pump, associated pipe work, hoses and a four-way valve. Pump(s) shall be adequate in size and volume to launch sphere-type displacers from the prover's launch chambers back into the calibrated section. Included on the waterdraw unit is a solenoid valve assembly, a control panel with detector switch indicator assembly, and a range of field standard test measures with a valve manifold for filling. The test measures are normally positioned so that they can be drained directly back into the reservoir. Single or multiple solenoid-valves may be used, and depending upon the piping configuration selected, two-way or three-way type solenoid valves may be used as required. The centrifugal pump circulates water from the reservoir through the prover. The water is then returned either into the field standard test measures and/or back into the reservoir. The calibrated test measures may each be filled and drained once, or many times during a calibration run, depending upon the volume of the prover. To reduce the uncertainty caused by test measure scale reading errors, the number of test measures filled during a calibration pass shall be kept to the minimum possible, based upon the volume of the prover and the number and sizes of the test measures available.

The waterdraw unit should be located as close as possible to the prover to be calibrated, within logistical constraints and safety considerations, in order to keep the hose connections as short as possible. This will greatly help to minimize any possible temperature variations, any excessive pressure differentials, and will also assist in keeping to a minimum the volume of water contained between the second detector switch and the inlet to the test measures. If this water inventory is large then a small change in the temperature of this water volume from the beginning to the end of each calibration pass will have a significant effect on the resulting prover volumes. See Appendix B for a full discussion of this effect.

6.1.6 Field Standard Test Measures

6.1.6.1 General Description

A field standard test measure is a vessel fabricated to meet API *MPMS* Chapter 4.7 criteria and calibrated by the National Institutes of Technology (NIST) or other national metrology institute. Its primary purpose is to provide a standardized volume, used for the calibration of displacement and tank provers, when calibrated by the waterdraw method. Specifications for test measures

shall be in accordance with the latest edition of the API *MPMS* Chapter 4, Section 7, “Field Standard Test Measures.” In addition the latest edition of the National Institute of Standards and Technology, Handbook 105, Section 3, *Specifications and Tolerances for Graduated Neck-Type Field Standards* may also be consulted for specifications.

Test measures are constructed of stainless steel ranging in sizes from one gallon to 1,500 gallons. In practice, the 500-gallon is the largest size test measure in regular commercial use, while the 100-gallon and 50-gallon are the test measure sizes used commonly. Test measures may be built in any convenient size, or in particular sizes, according to specific requirements and distinct prover volume sizes. Only test measures calibrated “to deliver” shall be used in the calibration of meter provers. Most test measures are filled through the top but that does not exclude the use of bottom filling test measures, provided that precautions are taken to detect any leakage through a closed bottom filling valve. A bottom filling arrangement for test measures is shown in Figure 5. Detailed descriptions of the utilization of field standard test measures can be found in Appendix D.

6.1.6.2 Calibration

Field standard test measures provide a primary link in the traceability chain to the National Institute for Standards and Technology (NIST). A Report of Calibration provided by NIST for each test measure shall be supplied to its owner, together with a copy of all the data obtained and used during the calibration and calculation procedures. The actual “to deliver” (some Reports of Calibration include both the “to contain” and the “to deliver” volumes) capacity of the test measure as shown on the Report of Calibration, shall be used as the official base volume of the test measure rather than the nominal volume. The NIST test measure seal numbers, cubical coefficient of thermal expansion, base temperature, method of calibration (gravimetric or volumetric) and the percentage volume uncertainty of each test measure used, are also stated on the Report of Calibration. Each field standard test measure shall have a current calibration certificate as defined in the latest edition of API *MPMS* Chapter 4.7, “Field Standard Test Measures” (e.g., within the last three (3) years per API *MPMS* Chapter 4.7, 2nd Edition, December 1998).

Each time a test measure is used it should be inspected for any signs of physical damage (e.g. dents, broken NIST seals, etc.) that may compromise its calibration integrity. Test measures shall be rejected any time there is significant evidence of damage, distortion, repairs, alterations or maintenance to the test measure that could affect its volume, unless verification of the previous volume, or a new re-calibrated volume, is provided.

6.1.6.3 Scale Readings

The water level on the scale of a field standard test measure is read with the eyes in a horizontal plane level with the bottom of the meniscus in the sight glass. Scale readings may occur anywhere above or below the zero mark. After the liquid level is read, the base measure volume (BMV) is then adjusted mathematically using a plus or minus liquid level (volume) scale reading.

The scale of a normal sensitivity test measure is read to a discrimination that is in a range from 0.2 in.³ to 5 in.³. The scale of a high sensitivity test measure is read to a discrimination that is within a range from 0.1 in.³ to 1.0 in.³. The maximum discrimination in any case would be to 0.1 cubic inches, and the minimum discrimination would be to $\frac{1}{2}$ a scale division. See Table D–2 in Appendix D for further guidance. Various techniques may be used to determine the water volume (scale reading) in a field standard test measure. Any of the following methods can be used; however, Method 3 is the normal operating practice used today.

- Method 1: Fill each test measure to its exact certified (zero) capacity, and allow the final water level to be read on completion in the last test measure filled.
- Method 2: Slightly overfill each test measure and then bring the level back to the exact capacity (zero) by withdrawing some of the liquid. The liquid that is withdrawn is then released into the next test measure to be filled.
- Method 3: With graduated neck test measures it is not necessary to operate at the zero level. Therefore, the test measure may be filled to any location on its scale, the liquid level read, and its certified capacity is then adjusted mathematically using a plus or minus scale reading ($\pm$ SR). A minus signifies that the water level is below the certified capacity (zero mark) on the test measure scale, and a plus indicates that the water level is above the zero mark on the scale.

6.1.6.4 Draining

Field standard test measures are calibrated with water and they are usually calibrated wet, “to deliver”, so that they may be used in a continuous manner without drying each time. Following the exact drain down procedure as specified by the calibrating agency is an essential part of the definition of the “to deliver” volume on the Report of Calibration. The words “cessation of the main

flow” describe a single dramatic event that occurs abruptly and can easily be determined. No distinction is made between a trickle and a fast drip, however, the change over usually occurs from the full discharging water flow to a trickle, almost instantly, and is very easy to recognize.

Test measures with a solid bottom arrangement, normally ten gallons or less, are emptied, by inverting the measure to a specified angle (e.g., 70 degrees). At the cessation of the main flow, the draining is continued for a specified time (e.g., ten seconds), and the test measure is then returned to an upright position, ready for use. The drain time and inversion angle specified on the Report of Calibration, for each test measure in use, shall always be followed.

Larger test measures, normally ten gallons or more, have a conical bottom, a center drain line and a bottom drain valve. Opening the drain valve, and allowing the water to drain until the cessation of the main flow, empties the test measures. Draining is then continued for an additional specified time (e.g., 30 seconds). The drain time specified on the Report of Calibration, for each test measure in use, shall always be followed.

6.1.6.5 Test Measure Selection

Prior to the calibration of the prover it is necessary to ascertain the sizes and numbers of the test measures available on the water draw calibration unit and the filling and rotation sequence that can best be used for these available test measures. These requirements can be determined from the known or estimated volume of the prover together with the filling and draining times of the test measures. In the case of a new or modified prover, it is sometimes beneficial to make an unofficial pass to determine the approximate volume of the prover and to establish a convenient filling order for the available test measures.

From all the test measures available for the calibration, several shall be chosen to best accommodate the displaced volume, and which will allow for filling and draining while maintaining continuous flow where possible, with a minimum number of test measure fillings.

Once the test measures have been selected for use, their filling order, including the size of the last test measure to be filled is immaterial, and has no influence on the overall uncertainty of the volume for any given pass. However, the size of the neck volume of the ending test measure should exceed the allowed tolerance for a given pass. The filling order does need to be addressed however, in order to maintain a smooth filling operation, without significantly surging the flow rate, or causing the displacer to stop and start too often. In order to reach the specified flow rate as quickly as possible, waterdraw passes typically commence in the medium or larger sized test measures. After the first pass has been completed, the filling sequence can be reviewed for continuity and smoothness. It is considered practical to keep the test measure filling order in the same sequence on subsequent passes. However, if desired, changes to the filling order from one pass to the next can be made. This situation can occur when the observation data that is gathered from the first pass suggests a change in the filling order.

6.1.6.6 Leveling

When the liquid level of a field standard test measure is read through the sight glass adjacent to the scale, the test measure itself shall be level and full of water.

The NIST Report of Calibration of a field standard test measure, shall provide the criteria for determining the level state of any given test measure when filled with water. In case of any disagreement between the permanently mounted spirit levels and the use of a precision machinist’s spirit level across the top of the neck, the NIST Report of Calibration definition of the level position for that test measure shall apply.

6.1.6.7 Using Field Standard Test Measures for Waterdraw Calibrations

All field standard test measures being used in the calibration shall be visually inspected internally and externally before use to ascertain that their capacities have not been altered by dents, internal corrosion or surface deposits. In addition inspect each test measure carefully to make sure it is free of rust, broken seals, broken gauge glasses and scales, broken or missing levels, leaks or defective drain valves. Only test measures calibrated with a “to deliver” volume shall be used in the calibration of meter provers. All test measures to be used shall be clean on the inside so that contamination does not compromise their calibrated volume, or cause a change in their drain down characteristics.

During preparation, all the test measures to be used in the calibration must be “wetted”, that is they shall have their entire inside surfaces coated with water and then be drained. “Wetting” of the test measures means that they shall be totally filled with water. Once filled, ensure that the test measures are level in two axes of a horizontal plane. The level of the test measure should be veri-

fied each time that its liquid level is read. Drain all of the test measures in the same manner in which they were calibrated. That is, the draining times as prescribed on the Report of Calibration for each test measure. The prescribed drain time is that additional time to continue draining after the cessation of the main flow.

Typical prescribed draining times of NIST calibrated test measures, according to the present edition of API *MPMS* Chapter 4.7, are as follows:

- For invertible-type test measures—10 seconds.
- For bottom drain valve type test measures—30 seconds.

The prescribed drain time of test measures must be adhered to each time they are emptied in order to replicate the “to deliver” of its calibrated volume. It follows that they should not sit empty for extended periods of time because of evaporation. Cans that have been “wetted” before beginning a calibration pass should be re-filled within a reasonable amount of time since they were last drained in order to minimize evaporation effects. If there are delays in starting, then the test measure(s) shall be re-filled and then re-emptied in the prescribed manner.

The liquid level of a field standard test measure is read with the eyes in a horizontal plane that is perpendicular to the bottom of the meniscus of the water in the sight glass. Visual aids that aid in determining the exact intersection of the bottom of the water meniscus with the horizontal plane perpendicular to the sight glass gauge scale are sometimes helpful. This reading should take place as soon as possible after filling, but after all the air bubbles caused by agitation are dispersed from the sight glass.

6.1.6.8 Normal Test Measure Operations

Setting up test measures for calibration use in the field normally involves the following preparatory steps. Inspect all test measures to be used in the calibration for cleanliness, dents, unbroken sight glasses, scales and seals. After this inspection, all the test measures shall be leveled while they are in water-filled condition. After filling and leveling of the test measures, check for leaks in the entire system. Drain the test measure as specified on the Reports of Calibration. The test measures are now ready for calibration use.

During a normal calibration run, the test measure is filled with water to a scale reading in the sight glass. After closing off the test measure, allow the water to settle and verify that the measure is still level. Read the water level at the bottom of the meniscus and record this scale reading as a (+) or (–) neck volume, depending upon whether the reading is above (+) or below (–) the zero line on the scale. The temperature of the water in the test measure is then determined before draining or while the test measure is drained in the prescribed manner. The test measure is now ready for the next filling if required.

All scale readings and temperatures obtained during the calibration run/pass are recorded on a field data sheet for subsequent calculations.

6.1.6.9 Variations from Normal Test Measure Operations

Occasionally in field use, due to abnormal conditions test measures may need to be operated in a different manner from normal usage. Generally these conditions are identified as either requiring that a test measure be overfilled, under-filled, or possibly a combination of both, during a particular calibration run cycle. If any of these conditions should arise during a prover waterdraw calibration, the techniques described below can be used to help remedy the deficiency. See Appendix D for complete details.

6.1.6.9.1 Test Measure Pre-Fill Operation

Sometimes during a waterdraw calibration it is necessary to accurately determine the volume of a partially filled test measure. This determination can be made by a method known as pre-filling. Pre-filling is accomplished by first transferring water from a pre-filled smaller test measure into a larger test measure. The object is to bring the water drawn from the prover into the larger test measure up to a level that can be read on the gauge scale glass.

6.1.6.9.2 Test Measure Neck Draw Operation

Sometimes during a waterdraw calibration it is necessary to accurately determine a volume of water in excess of the capacity of the last test measure. This determination can be made by a method known as neck draw. First, lower the water level in the neck of the test measure to a lower level on the scale, and then re-fill the neck again to a higher level. It is possible that this procedure may have to be repeated several times in extreme cases to accommodate the excess water.

6.1.6.9.3 Combination Pre-Fill and Neck Draw Operations

It is also possible to have a situation where a test measure pre-fill and a test measure neck draw are both necessary during the same prover calibration run. Although this is not common, it is a situation of which operators should be aware.

6.1.7 Displacers

In displacement provers, displacers are used to form a seal between the upstream and downstream water volume. This displacer is moved by the water flow and pushed through the measuring section, where it actuates the detector switches that are used to define the volume of the prover. The most common type of displacer is the inflatable sphere.

Before the waterdraw calibration of the prover is started, the sphere displacer shall have been examined for condition and size. Once properly sized and coated with a thin film of a water-resistant lubricant, the sphere was installed in the launching chamber of the prover ready for the calibration. The purpose of the lubricant is to ensure that, while the sphere is operating at lower than normal flow rates during the waterdraw calibration, it will continue to move smoothly through the measuring section. A sphere moving with a shuddering or jumping motion during a pass/run can significantly impact the calibration results obtained.

Jumping, irregular, or shuddering motion of the sphere during a pass can usually be detected by fluctuating pressures on the pressure gauge, or by observing changing flow rates when all the water is passing through the solenoid valve and the sphere is approaching the detector switch. Possible causes of this erratic or irregular movement of the sphere are:

- Over-inflation of the sphere
- Under-inflation of the sphere
- Lower flow rates
- Lack of lubricant on the sphere

Trace hydrocarbons remaining on the interior walls of the prover pipe can be a cause of the failure of the sphere lubricant coating to ensure its smooth motion. In this situation of erratic sphere motion it may be necessary to stop the calibration and remove the sphere from the prover. Inflate or deflate the sphere as necessary, re-coat it with lubricant and then re-install in the prover. Repeat all the necessary procedures to restart the calibration.

Repeatability problems during calibration runs often require all aspects of sphere condition and inflation to be examined, up to and including its removal from the prover for inspection and correction.

Any changes to sphere conditions that affect the seal of the sphere or the actuation of the detector switches may alter the effective volume of the prover.

6.1.8 Water Quality

Water quality is very important in all waterdraw calibrations. It does not have to be pure distilled water as ordinary drinking water is excellent for calibration purposes. Dirty water, heavily aerated water, hydrocarbon contaminated water, salt water, or any water of inferior quality, can severely affect the capillary action of the meniscus, the surface tension action in the sight glass, the draining action of the test measure, or the amount of clingage retained by the test measures. All of these effects and others attributable to inferior quality water can have a detrimental effect on any successful prover calibration.

6.1.9 Air

Air must be vented from all high points in the system before beginning the calibration. This includes those high points, which are static during the calibration and which, because of varying pressures and the friction load on the displacer, can result in erratic displacements of water into the test measures. Passing the displacer around the prover with all the high point vents open to allow a trickle of water is a common method of ensuring that all air is removed from the system. The waterdraw concept of calibration depends upon a true hydraulic displacement, which is only possible in an air-free system.

6.1.10 Hydrocarbons

All hydrocarbons should have been removed from the system during the cleaning process. Any still present must be removed from the prover, and not be allowed to contaminate the test measures, before beginning the calibration. Even in static locations hydrocarbons adversely affect the quality of the water, change the expansion/contraction characteristics of the water in the system with temperature and pressure changes, and usually introduce gas into the system on a continuing basis.

6.1.11 Hoses, Pumps and Connections

The packing gland or mechanical seal in the circulating water pump, and all the inlet piping, shall be inspected for suction leaks. Suction leaks are especially problematic in allowing air to enter into the system.

If flexible hoses are being used they should be free of kinks, buckles and leaks. All the hoses should be of a non-collapsible type for reduced pressures and must have the same shape at the beginning and end of any calibration run. Rigid hoses are best for this purpose.

All the flexible hose connectors should have gaskets in good condition, unbroken locking arms or connectors, and all hose connections shall be leak free.

6.1.12 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, while filling and emptying the test measures. During all calibration passes it is desirable to keep the displacer moving smoothly at a constant flow rate as much as possible. If the flow must be stopped at any time (e.g., waiting to drain a test measure), the displacer should be stopped and restarted, in a horizontal plane, both smoothly and relatively quickly. Stopping the sphere in a bend or any place where the pipe is welded is not recommended. Logically, if there is no leakage past the sphere, it should make no difference whether or not it is halted during a calibration pass within the limitations stated above.

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
- That the solenoid valve opening is too small
- That there are hydrocarbons in the system
- That there is air in the system
- That the water pressure is improperly changing

The calibration shall be carried out at flow rates such that the test measures can be filled without surging, overflowing or splashing water out of the top. Any splashing, overflowing or other loss of water from these test measures will render the calibration pass invalid.

For leak detection and reproducibility purposes, the flow rate on displacement provers shall be changed between consecutive calibration runs by 25% or more (e.g., fast/slow/fast or slow/fast/slow):

- On unidirectional provers, the flow rate between consecutive calibration passes shall be changed by 25% or more.
- On bi-directional provers, the flow rate between consecutive calibration round trips shall be changed by 25% or more with the “out” (traveling away from home position) pass and “back” (returning to home position) pass for any given round trip always being at the same flow rate. The terms “left to right” and “right to left” are often used to describe the passes in two different directions. By convention, “left to right” and “right to left” are viewed from the end of the prover where the launching chambers and four-way valve are located. See Chapter 4, Section 9, Part 1, “Introduction to the Determination of the Volume of Displacement and Tank Provers,” Figure 1, “Bi-directional Prover Orientation of Left and Right”.

However, at the discretion and concurrence of the operators and represented parties, the specified order in which the calibration flow rates are changed may be altered (e.g., fast/fast/slow, fast/slow/slow, slow/fast/fast or slow/slow/fast). In any case, the flow rate for at least one of the runs on unidirectional provers shall be at a rate that represents a change of 25% or more from the other runs. On bi-directional provers, at least one of the passes in the “out” direction and at least one of the passes in the “back” direction shall be at a rate that represents a change of 25% or more from the other passes in their respective directions.

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

- Using a flow meter to monitor the flow rate while adjusting the filling valve(s)
- Timing the filling of the largest test measure being used.
- Timing the entire calibration pass [(total volume / time) = flow rate].

Regardless of the method used, a change of 25% or more to the flow rate applies to the entire calibration pass and not to just a portion of the pass. Consider the calibration of a 200-gallon prover with two 100 gallon test measures, in which a “fast” run was conducted by filling each test measure at a rate of 60 GPM. A 25% reduction in flow rate could be accomplished by filling each test

measure at 45 GPM which would be appropriate. However, an inappropriate approach would be to fill one of the test measures at 60 GPM and the other test measure at 30 GPM. Even though this would result in a calculated overall flow rate of 45 GPM, or a reduction of 25%, the criteria of applying the rate change to the entire calibration pass would not be met. If test measures of various sizes are used, it is understood that filling rates would vary between them. In that case, rate changes made would be relative to each measure being filled.

6.1.13 Number, Continuity and Sequence of Calibration Runs

At least three consecutive calibration runs, that meet all the repeatability criteria, are required for the successful calibration of displacement provers.

Two consecutive calibration runs, that meet all the repeatability criteria, are required for a successful tank prover calibration. However, if the calibration scale is moved, then a third calibration run is required.

If any single calibration run does not meet the repeatability criteria, the reason must be ascertained, remedied, and the calibration continued until the repeatability criteria of an unbroken chain of three consecutive calibration runs is achieved.

- A calibration run on a unidirectional prover is a one way pass.
- A calibration run on a bi-directional prover is a round trip.
- A calibration run on a tank prover is one filling or emptying.

Any measured pass is part of the consecutive chain. However, in the case of mishaps, such as, the overflowing of a test measure, 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 started over.

Re-starting a pass can only be done in a stable temperature condition. Therefore, it may be necessary to return the displacer to the launching chamber before beginning the repeated pass. When a single pass breaks the consecutive chain, either that pass, or the next, may be used to start the next consecutive chain.

Consecutive passes are defined as sequential measured passes. Due to constraints of time, weather, or other external factors, it is sometimes necessary to suspend the waterdraw calibration between passes. To restart the calibration process the following procedures may be required depending upon the length of time the calibration is suspended:

- The displacer shall be flexed by conducting at least one unmeasured pass.
- Care must be taken to ensure that flowing conditions and temperature are stabilized.
- All test measures shall be refilled, leveled and drained per requirements.
- All vents shall be checked for air and the system rechecked for leaks.
- The flow rate required for the calibration shall continue in the established sequence.

In the case of a sudden shutdown of the system during a calibration pass (e.g., pump failure, electrical failure, etc.), the test measure filling-valve shall immediately be closed so that air is not pulled into the system. If flow can be restored within a very short period of time (e.g., re-setting an electrical breaker etc.) then the pass can be continued. However, should a longer period of time be required to restore the system (e.g., replacement of the pump, restoration of the electrical power, etc.), then the procedure for a mishap to the pass, or the procedure for the suspension of a calibration, shall be followed. However, if the delay will be protracted, then the calibration shall be abandoned and restarted when the system has been fully restored.

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 waterdraw calibration. Each calibration shall meet the same criteria as described above. Reference Figure 2 in API MPMS Chapter 4, Section 9, Part 1, Introduction, for various detector switch configurations on multiple volume provers.

6.1.14 Calculations and Repeatability

Detailed calculation procedures are not included in this standard. For the complete details of the waterdraw method calculations, applicable to this standard, refer to the latest edition of the API MPMS, Chapter 12, Section 2, Part 4, "Calculation of Base Prover Volumes by the Waterdraw Method."

The Calibrated Prover Volume (CPV) of a unidirectional prover is the corrected volume displaced in passing the displacer from one detector switch to a second detector switch, always in the same direction. The described one-way procedure should be repeated until satisfactory repeatability of at least three calibration pass/runs is achieved. The average value of three or more con-

secutive one-way corrected volumes is considered the Base Prover Volume (BPV). The corrected volumes for all three or more consecutive calibration runs shall agree within a range of 0.020%.

The Calibrated Prover Volume (CPV) of a bi-directional prover is the corrected volume displaced in passing the displacer from the first detector switch (Detector Switch “A”) to the second detector switch (Detector Switch “B”), followed by the corrected volume displaced in passing the displacer from Detector Switch “B” back to Detector Switch “A”. These two consecutive single passes, in opposite directions, constitute a single round trip volume. The average value of three or more consecutive round-trip corrected volumes is considered to be the Base Prover Volume (BPV). The corrected volumes of three or more consecutive round trip runs shall agree within a range of 0.020%; the corrected volumes of three or more consecutive passes in the “out” direction, making up those round trips, shall agree within a range of 0.020%; and the corrected volumes of three or more consecutive passes in the “back” direction, making up those round trips, shall also agree within a range of 0.020%.

The Calibrated Prover Volume (CPV) of an atmospheric tank prover is the corrected volume measured between an upper liquid level and the lower level. The calibration shall be repeated until two or more consecutive volumes, after corrections, agree within a range of 0.020%. The average of the consecutive tank prover volumes shall be used as the initial calibrated volume of the tank prover, which is the volume between the upper reference level and the lower level. The upper neck scale and/or the lower neck scale should then be aligned so that the calibrated volume of the tank prover at the reference level aligns with the scale reading for that volume. Some tank provers have an upper scale that reads in + or – increments from a zero mark (similar to field standard test measures). Following the adjustment of the upper neck scale and/or lower neck scale, a final calibration run is made to verify that the scale adjustment is correct within 0.010% of the target volume (e.g., 500 gallons, 1000 gallons, etc.). In that case, the Base Prover Volume (BPV) is considered to be equal to the target volume. In the case where no adjustments are made to either scale, the average value of three or more consecutive corrected volumes is considered to be the Base Prover Volume (BPV). The corrected volumes for three or more consecutive calibration runs shall agree within a range of 0.020%.

Repeatability between the results of consecutive prover volumes (passes and runs) at standard conditions is calculated from the formula:

$$R = \left[\frac{(MaxCPV - MinCPV)}{(MinCPV)} \right] \times 100$$

For additional information refer to the API *MPMS*, Chapter 12, Section 2, Part 4, “Calculation of Base Prover Volumes by the Waterdraw Method”, for complete details on the determination of repeatability.

6.1.15 Calibration Certificate Package

All observation data shall be hand written in ink/ or collected, recorded, and reported automatically by a flow computer with audit trail capability. All the observation data shall be proof read against the input calculation data before signing the documents. In case of discrepancies or errors discovered at a later date the hand written observation data shall be used to correct the final volume. See Appendix C for examples of waterdraw calibration data sheets.

The calibration certificate package shall include the Calibration Report with the Date of the Prover Calibration prominently displayed on the front of the Calibration Certificate Package. Other items applicable to the calibration shall also be recorded in the Calibration Certificate Package as follows:

- the field standard test measures used
- the temperature indicators and pressure indicator used
- the location of the prover
- the owner or operator of the prover
- the serial number of the prover
- the material of construction of the prover
- the inside diameter of the prover
- the wall thickness of the prover
- the displacer type, durometer (if available), and the size
- the type of prover
- in the case of multi-volume displacement provers
 - a clear identification of the detectors used for this calibration

- the physical location of each detector
- A copy of the final calculation and summary documentation
- A copy of the handwritten observation documentation (signed by all parties as witness to the original observation data)
- Copies of the NIST Reports of Calibration for all of the field standard test measures used
- Calibration Certificates for all the temperature and pressure indicators used

6.2 DISPLACEMENT TYPE UNIDIRECTIONAL PROVERS WITH FREE DISPLACERS

A unidirectional prover with a free displacer operates with some type of sphere handling interchange. If this interchange is left in place during the waterdraw calibration, then it is normally used to launch the sphere for each calibration pass/run. At the end of its pass/run the sphere is allowed to continue into the interchange to await its next launching.

Before beginning a calibration on any unidirectional displacement prover with a free displacer, the air must be vented at all high points. This includes those points, which are static during the calibration. All venting shall be done before, during, and after moving the sphere through the prover several times, by leaving the vents partially open and continuously bleeding off air and water.

Unidirectional provers with sphere interchanges require special attention in that all the air must be vented with the interchange in both the open and sealed positions. This shall be done before, during, and after moving the sphere through the prover several times, by leaving the vents partially open and continuously bleeding off air and water.

With the interchange in place and functioning, the calibration can be performed using the normal operation to launch and receive the sphere displacer. To improve air elimination and temperature stability the sphere should be allowed to complete its forward travel at the end of a calibration pass, and be sent through the interchange for a re-launch from the launching chamber.

A four-way valve is usually located between the prover and the waterdraw unit for sphere positioning purposes at the first detector switch. All measured calibration pass/runs shall be made in the same direction as in normal prover operation. A trial run is sometimes made to work out any operational details and verify the approximate prover volume (especially on new provers).

Sometimes, the interchange is removed for the period of the calibration and replaced with a blind flange equipped with a connection to serve as the prover water inlet. In that case the sphere has to be placed into the prover pipe prior to the fitting of the blind flange. At the end of each pass/run, a four-way valve, located on or near the waterdraw unit, is used to return the sphere back to its starting position. On other occasions the sphere interchange may be removed or blinded-off from the remainder of the prover, and the sphere traversed inside the pipe between the prover detector switches. When the calibration is performed in this way the sphere is kept in the pipe section of the prover at all times and special care must be exercised to ensure the complete evacuation of air. After the displacer has been launched and completed its calibration run, a four-way valve is required to return the sphere displacer back to its starting position upstream of the first detector. Therefore, when using a four-way valve to return the sphere to the starting detector, the return pass is not measured. It is essential that all calibration runs be conducted in the same direction that the displacer normally travels.

Regardless of whether an interchange is being used or not, a four-way valve is required to position the sphere at the starting detector. See Figure 1.

On the first pass the following starting sequence is followed to position the sphere into its starting position under the first detector switch. The detector switches are named “A” and “B”.

1. The sphere is directed FORWARD to Detector A at normal flow rate, until it passes completely through this detector. Closing the circulation block valve then stops the flow.
2. The direction of the flow is changed to REVERSE using the four-way valve.
3. The circulation block valve is re-opened and the sphere is now traveling in the REVERSE direction back through Detector A for a short distance until the audible or visual signal (if used) ceases. Closing the circulation block valve again stops the flow.
4. The direction of the flow is changed to FORWARD using the four-way valve.
5. The water flow is now directed through the solenoid valve, in the FORWARD direction. All the water is now passing only through the solenoid valve at a very slow flow rate.
6. At this time the pressure of the system shall be read on the downstream side of the displacer, by means of a pressure gauge that is usually installed on the waterdraw calibration unit manifold.
7. When Detector A is actuated, the solenoid valve operates and the water flow is directed into the first test measure.

The above procedure starts the filling of the first test measure. Continue until this test measure is almost full. At this time slow the filling rate into the first test measure, and at the same time direct the water into the second test measure. The second test measure is now being filled and the first test measure, being full, is closed off. If necessary the water level in the first test measure can be adjusted to a desired scale reading by the addition of water through the small filling valve. The water level in the first test measure is allowed to stabilize, the test measure is checked for level, its liquid level is read, and the temperature taken before or during draining. The test measure is then drained, in the prescribed manner.

When the second test measure is almost full, its rate is slowed, and at the same time water is directed, either back to the first test measure, or to another test measure. Once this test measure is being filled, the second test measure is closed off when the water level reaches the scale. Allow the water level to stabilize, check the test measure for level, read the liquid level on the scale and take the temperature before or during draining. The test measure is then drained in the prescribed manner.

This procedure is continued until the last test measure is being filled. When the water level reaches near to the neck of this last test measure, the main filling valve is closed off and all the water being discharged is directed back through a solenoid valve ready for an automatic shut-off at the end of the calibration pass. Once the sphere contacts the Detector B, the solenoid valve will close and the water flow into the last test measure ceases. Open the water flow to reservoir and allow the sphere to continue to pass on through Detector B.

If the sphere interchange is being used then the sphere continues to pass and will reposition itself in the receiving chamber. If the interchange is isolated or removed, then by means of the four-way valve reverse the flow. Return the displacer back around the prover calibrated section, to the upstream side of Detector A, ready to start the next pass.

The prover temperature shall be taken downstream of the second detector, at the beginning of each pass, after the sphere has passed the first detector, and after the temperature has stabilized but before it has traveled a third of the distance between the detectors. The prover pressure is taken at the beginning of each pass, downstream of the displacer, while the ball is slowly approaching the starting detector, and the water flow is being discharged only through the solenoid valve.

The calibration will end when there are three consecutive successful runs meeting the established repeatability criteria.

In all unidirectional provers, detector switch settings are critical and any adjustments will affect the prover volume. Once the calibration has been successfully completed it is recommended that the detectors be sealed in place. No adjustment of the detectors after starting the calibration is permitted. Any adjustment of the detectors following a calibration will necessitate a recalibration of the prover.

If there is difficulty in launching the ball from the launching chamber at low flow rates, it may be necessary to put two circulating pumps in parallel at least for an initial launch. This may even require starting from a less than full condition. If this is done the ball must then be run back and forth while venting all high points until all the air is evacuated and the prover refilled with water. The sphere interchange must be checked for leakage, before and at the end of each calibration run, to ensure there is no bypass through the interchange.

6.3 DISPLACEMENT TYPE BI-DIRECTIONAL PROVERS WITH FREE DISPLACERS

This section discusses provers that operate on a round-trip basis. The waterdraw calibration of a bi-directional prover is essentially the same as a unidirectional prover except that two calibration passes, in opposite directions, are required to make up a round trip run. These calibration passes, in opposite directions, do not necessarily have to agree in volume. However, all the calibration passes in the same direction, as well as all the calibration round trip runs, shall be in agreement within a range of 0.020%.

A four-way valve is required for the calibration of a bi-directional prover. If the four-way valve located on the prover being calibrated is used in the calibration, then it shall be checked for sealing integrity after each operation. Alternatively, an auxiliary four-way valve, located on or near the waterdraw unit may be used as an alternative. Whichever four-way valve is used it shall be checked for sealing integrity after each operation. If the four-way valve on the waterdraw unit is used then the four-way valve on the prover being calibrated shall be secured in one direction, leak tested, and left in place. Sometimes the four-way valve from the prover being calibrated is removed or blinded off. A trial run is sometimes helpful to work out any operational details.

Before beginning a calibration on any bi-directional displacement prover with a free displacer, the air must be vented at all high points. This includes those points, which are static during the calibration. All venting shall be done before, during, and after moving the displacer through the prover several times, by leaving the vents partially open and continuously bleeding off air and water.

Bi-directional provers with 45° launching chambers often require special attention when venting. The vent points in the ends of the launch chambers are constructed at a lower level than the top of the chamber, permitting air to be retained, which cannot be vented by ordinary means. When this occurs it may be necessary to actually loosen the end flange or door closures to complete venting of this area. The same principle of breaking open bolts, flanges or appliances holds true in other high point situations where vents are not provided.

Calibration passes through the bi-directional prover may be made using the permanently mounted four-way valve, or by using the smaller four-way valve mounted on the waterdraw unit. Owner/operator preference normally decides whether to use the permanently mounted prover four-way valve in the calibration, blind it off, or leave it permanently locked to one side or the other. Some operators prefer to use the smaller four-way valve on the waterdraw unit. Unless the large four-way valve is blinded off, both four-way valves must be checked for leakage before, and at the end of each calibration pass, to ensure there is no leakage through either of the valves. See Figures 2A and 2B.

Because bi-directional provers have a round-trip calibrated volume, consisting of both an “out” pass and a “back” pass, detector switch settings are not considered as critical as in unidirectional provers, assuming that each detector is truly bi-directional in its operation. Detectors must not be adjusted between any of the calibration runs. In the detector, the centerline of primary actuation is critical, just as in a unidirectional prover. Any adjustment of a detector switch will affect both the “out” and “back” volumes.

Each calibration run (round-trip) consists of an “out” and “back” pass. Both passes must be completed, at the same flow rate, to successfully complete a calibration run. Three consecutive round-trip runs are required for a successful bi-directional prover calibration.

It is essential that all calibration passes be conducted in the same manner as the prover is normally operated. Therefore, two consecutive passes shall never be made in the same direction. Ideally, for air elimination and temperature stability purposes, the displacer should be allowed to complete its travel at the end of any given calibration pass and return to the launching chamber. After that, it can again be repositioned at the starting detector position, ready for the next pass.

On the first pass the following starting sequence is followed to position the sphere into its starting position under the first detector switch. The detector switches are named “A” and “B”.

1. The sphere is directed FORWARD to Detector A at normal flow rate, until it passes completely through this detector. Closing the circulation block valve then stops the flow.
2. The direction of the flow is changed to REVERSE using the four-way valve.
3. The circulation block valve is re-opened and the sphere is now traveling in the REVERSE direction back through Detector A for a short distance until the audible or visual signal (if used) ceases. Closing the circulation block valve again stops the flow.
4. The direction of the flow is changed to FORWARD using the four-way valve.
5. The water flow is now directed through the solenoid valve, in the FORWARD direction. All the water is now passing only through the solenoid valve at a very slow flow rate.
6. At this time the pressure of the system shall be read on the downstream side of the displacer, by means of a pressure gauge that is usually installed on the waterdraw calibration unit manifold.
7. When Detector A is actuated, the solenoid valve operates and the water flow is directed into the first test measure.

The above procedure starts the filling of the first test measure. Continue until this test measure is almost full. At this time slow the filling rate into the first test measure, and at the same time direct the water into the second test measure. The second test measure is now being filled and the first test measure, being full, is closed off. If necessary the water level in the first test measure can be adjusted to a desired scale reading by the addition of water through the small filling valve. The water level in the first test measure is allowed to stabilize, the test measure is checked for level, its liquid level is read, and the temperature taken before or during draining. The test measure is then drained in the prescribed manner.

When the second test measure is almost full, its rate is slowed, and at the same time water is directed, either back to the first test measure, or to another test measure. Once this test measure is being filled, the second test measure is closed off when the water level reaches the scale. Allow the water level to stabilize, check the test measure for level, read the liquid level on the scale and take the temperature before or during draining. The test measure is then drained in the prescribed manner.

This procedure is continued until the last test measure is being filled. When the water level reaches near to the neck of this last test measure, the main filling valve is closed off, and all the water being discharged is directed back through a solenoid valve, ready for an automatic shut-off at the end of the calibration pass. Once the displacer contacts Detector B, the solenoid valve will close

and the water flow into the last test measure ceases. Open the water flow to drain, and allow the sphere to continue on through Detector B into the launching chamber. If the temperature is stable on a large prover, in order to save time between passes it may be possible to hold the displacer downstream of Detector B between passes. However doing so indiscriminately may result in unrepresentative prover temperatures, so care must be exercised.

The displacer should then be repositioned back to Detector B, ready for the commencement of the “back” pass, which will be conducted in exactly the same manner as the “out” pass described above, but in the reverse direction.

The prover temperature shall be taken downstream of the ending detector, at the beginning of each pass, after the displacer has passed the starting detector, and after the temperature has stabilized, but before it has traveled a third of the distance between the detectors. The prover pressure is taken at the beginning of each pass, downstream of the displacer, while the sphere is slowly approaching the starting detector for the “out” pass, and all the water is being discharged through the solenoid valve.

At the end of a successful calibration there should be three consecutive round-trip runs, consisting of six consecutive passes, all meeting the repeatability requirements, for example, labeled as follows:

“Out” Pass 1: “Back” Pass 2:= Round-trip 1

“Out” Pass 3: “Back” Pass 4:= Round-trip 2

“Out” Pass 5: “Back” Pass 6:= Round-trip 3

6.4 DISPLACEMENT TYPE METER PROVERS WITH CAPTIVE DISPLACERS

Some types of displacement provers have shafts attached to the displacer. These shafts may be continuous on both sides of the displacer, or they may be on only one side of the displacer. If the shafts are continuous and uniform in diameter on both sides of the displacer then the effective upstream volume (i.e., when the flow meter being proved is upstream of the prover) may be equal to the effective downstream volume (i.e., when the flow meter being proved is downstream of the prover). However, if the shafts are on only one side of the displacer, then the effective upstream volume will differ from the effective downstream volume. For further explanation, if the shaft is only on the upstream side of the displacer, the effective volume when a meter is proved upstream of the prover will be less than the effective volume when a meter is proved downstream of the prover. Conversely, if the shaft is only on the downstream side of the displacer, the effective volume when a meter is proved upstream of the prover will be greater than the effective volume when a meter is proved downstream of the prover. The difference in volumes is equivalent to the volume displaced by the shaft. Both volumes shall therefore be stated on the calibration certificate package(s). If only one volume is determined, the calibration certificate package shall clearly state this, and identify the side of the prover that is calibrated to ensure that only meters on this side of the prover are to be proved with this prover.

It is strongly recommended that in this type of prover both upstream and downstream prover volumes be determined. In that case, both volumes shall be determined by calibration, and both volumes shall be reported on the Calibration Certificate Package(s). The downstream volume is normally calibrated in its normal flow pattern. However, the upstream volume is often calibrated “backwards” meaning that in a unidirectional prover the displacement is from Detector Switch “B” to Detector Switch “A”.

Calibrating the upstream volume in this manner may require changing a setting in the prover controller so that:

- Seal integrity is maintained while the displacer is measuring in the “reverse” direction.
- The opposite side of the detector switch (leading vs. lagging) is used for the upstream volume so that any distortion caused by changing the direction of displacement is eliminated.

It has been found that using a four-way valve is very useful for calibrating the upstream volume of a unidirectional displacement prover with a captive displacer. Advice from the manufacturer in this procedure is highly recommended. Insertion detector switches on a pipe prover with a free displacer are usually connected in parallel using “normally open” contact switches. However, provers with captive displacers often require the use of a relay and connections to “normally closed” contact switches. Usually the manufacturer can provide a special kit for waterdraw calibration, unique to their type of prover.

As the volumes on this type of prover are small, three-way solenoid valves are normally used so that a measured run can be made without stopping the displacer at the detector switch. Field personnel, waterdraw technicians and observers should have a complete understanding of the equipment and procedures to be used on the calibration of displacement provers with captive displacers.

These types of provers are calibrated just like the displacement provers with free displacers with certain differences. Some of the features to note about provers with captive displacers are as follows:

- A captive displacer with a shaft assembly only on one end of the displacer will require the calibration of both an upstream volume and a downstream volume, so that the prover can be used to prove meters located both upstream and downstream. One of these volumes can be calibrated with the flow in its normal direction. The other volume may require that the calibration be performed in the opposite direction. See Figures 3A and 3B.
- Some prover designs allow for the calibration of this volume by the use of optical detectors, which gate at the same point regardless of direction. Optical detectors allow these provers to have smaller physical sizes and volumes than most other types of displacement provers.
- The water inventory from the ending detector to the test measure is a major factor in this type of calibration. To minimize the effects of this water inventory, the waterdraw unit should be as close as possible to the prover, and the use of smaller lines should be considered. See Appendix B.
- A single test measure is preferred that will accommodate the displaced volume between the detectors of the prover.
- A single test measure, with a high sensitive neck, is recommended for any prover less than 25 gallons.
- A captive displacer with shafts of the same diameter on both ends of the displacer may require only one calibration in a uni-directional prover. See Figure 3C.
- Waterdraw calibration shall be used to determine both upstream and downstream prover volumes. Theoretical type calculated volumes shall not be used.
- In addition to the temperature (T_p) of the water between the detectors, which is taken in the same way as for a displacement prover with a free displacer, it is necessary to determine the temperature (T_d) of the external detector mounting assembly (e.g., bar). This can be done by shading the prover during the calibration and determining its ambient temperature at the same time that the prover water temperature is determined for each pass. If it is desired to take a direct temperature of a detector mounting bar, the temperature device used for this purpose should be thermally bonded to the detector mounting bar. In any case, it is recommended that the prover be shielded from direct sunlight during the calibration.

Before beginning a calibration on any displacement prover with a captive displacer, the air must be vented at all high points. This includes those points, which are static during the calibration. All venting shall be done before, during, and after moving the displacer through the prover several times, by leaving the vents partially open and continuously bleeding off air and water.

6.5 ATMOSPHERIC TANK PROVERS

6.5.1 Tank Prover Calibration Procedures

All tank provers have an upper scale. Some of them drain to a fixed zero, and some have a lower scale graduated with a zero position. The exact nature of this zero position must be determined so that the manner, in which the prover is calibrated, agrees with the manner in which it is ultimately used.

The waterdraw calibration procedure is similar to that which is used in calibrating pipe provers, including the taking of the temperature on the prover at the beginning of the run. The prover temperature is taken just before taking the scale reading in the top neck for that run. Since both the open tank prover and the field standard test measures are at atmospheric pressure, there is no pressure reading to be taken. In calibrating a volumetric tank prover, continuous circulation is not made, but rather a filling and then a draining of the volumetric tank into the test measures. The start and stop is controlled manually or semi-automatically (while observing the scale reading) rather than automatically through detector switch and solenoid-valve combinations. On new tank provers, the neck scale increments shall also be calibrated. When the tank prover is re-calibrated, verify the neck scale.

An open tank prover may also be calibrated by water-fill, rather than by waterdraw, if it is practical to raise and support the test measures on a level plane above the tank prover. In this case the temperature of each test measure is determined by immersion of the temperature device into the test measure. The temperature device shall be withdrawn immediately prior to reading the test measure scale. The test measure is then drained into the tank prover in the prescribed manner. The temperature of the tank prover is taken at the end of the run, after reading the top neck scale.

If there is sufficient water available so that the test measures can be filled in a timely and efficient manner; and the logistics of raising the test measures overhead of the tank prover in a level condition have been worked out; then water-fill is the preferred method of calibration of the tank prover. This is because it more closely replicates the normal operating drain time of the tank prover. Calibrating by water fill has the advantage that the drain-down of the tank prover after each calibration run approximates the way the volumetric prover tank is actually used. The tank prover must be filled and drained once just prior to beginning a cal-