FUNDAMENTALS OF METER PROVERS AND PROVING METHODS

Greg Williams

Flow Management Devices

Introduction:

This document will provide the reader an understanding of what a prover is, the need for proving meters for accurate measurement uncertainty verification, the equipment deemed acceptable and available for use in the oil and liquefied gas market. It will also define the general terminology used in the industry, general operational aspects for verification devices, and general information utilized by the groups and agencies that govern the meter verification process.

What is a meter prover?

A meter prover is a device used to verify flow meter uncertainty in order to establish;
- the K-Factor (Pulses per unit volume) of a meter
- the Meter Factor of a meter (factor used with a meter to correct accuracy for ambient conditions)
- the Linearity over the calibrated flow range for the meter
- the Repeatability for the meter system

The meter factor is obtained by dividing the prover test volume by the indicated volume of the meter. Once the meter factor is determined it is used as a volume correction in the calculation for net standard volume of a receipt or delivery of liquids.

$$\text{(Mfg. or Last) Meter Factor} \times \frac{\text{Volume Measured By the Meter}}{\text{Actual Volume Passed Thru Prover}} = \text{New Meter Factor} \qquad \text{(Equation 1)}$$

Why companies prove flow meters?

The purpose for meter verification or meter proving is to provide accurate measurement which then will minimize losses and maximize profits. The flow metering systems are the “cash registers” for all petroleum operations and this means errors in meter factors can and will generate enormous financial errors in a company’s invoicing in a short period of time!

Example:

If we look at the following example is becomes clear how much money is involved.

- An 8 inch crude line delivering product to a Refinery, at a flow rate of 2150 Barrels/Hour (BPH).
- The flow meter used in the line, which was proved using a Master Meter, is found to be inaccurate by 0.25% and the crude wholesales for $ 35 per Barrel.
- In 1 month the product was incorrectly invoiced to the amount of:
  2150 X 24 hours X 30 days X .0025 error factor X $35/barrel = $ 135,450.00, miss invoiced – per month, every month the meters are left uncorrected.

It should now be clear how important meter proving is to the petroleum business.

Classification of Volumetric Proving:

To differentiate between the classifications of volumetric meter proving the terms **static** and **dynamic** will be defined. The difference applies to the way the standard is compared with the reading of the flow meter under test.

In the **static** scenario the fluid is collected in a test vessel and compared to the gross delivered amount of the meter under test. This is normally an open system and will require interruption of the flow process to perform the meter factor verification.
In the **dynamic** scenario the fluid remains in a closed system whereby the pulse registration of the meter under test and the pulse registration of the standard prover used are compared directly. There is no interruption of the normal flow process during this verification of the meter factor.

Equipment used for Proving:

There are three types of measurement equipment used for verification in the petroleum industry today, test measure **tank provers, volume displacement provers**, and **master meters**. Decisions for which type of equipment should be used are based on accuracy requirements, testing flow rates, measurement turndown requirements, environment, cost to install, cost to maintain, and in some cases local agency approvals.

Prior to the development of the volume displacement prover, the volumetric **test measure tank prover** was the only product available for volume measurement verification and has been around since the turn of the 20^{th} century. The volume tank prover may be used for the calibration of liquid flow meters; and is also approved for performing a volumetric water draw calibration of volume displacement provers per API MPMS Chapter 4.9.

The **master meter prover** has unlimited applications for proving and is noted in the API MPMS Chapter 4.5. Although used in the industry for some time, it does not have total acceptance for custody transfer approval or for use in weights and measures type applications by all local or regional agencies. The required verification of the master meter's accuracy can be established by using a displacement type or a volumetric tank prover. This should be completed prior to the start of any transfer when product characteristics (products, temperature, pressure, density, viscosity) have changed since last master meter use.

The petroleum industry and American Petroleum Institute (API) have accepted the use of **volume displacement provers** in two categories. The **conventional pipe prover** is a displacement prover with sufficient reference volume to accumulate 10,000 whole pulses in a single pass; and the **captive displacement or small volume prover** (SVP) is a displacement prover with insufficient reference volume to accumulate 10,000 pulses in a single pass and uses pulse interpolation software). In both cases, it will require multiply passes for a proving and to establish as new meter factor. The conventional provers have been utilized for meter proving since the early 1950's and the captive displacement prover entered the market in the mid 1970's after the acceptance of the double chronometry or pulse interpolation (techniques which whole meter is counted between detector switch one and detector switch two and any remaining fraction of a pulse in calculated) as identified in API MPMS Chapter 4.6.

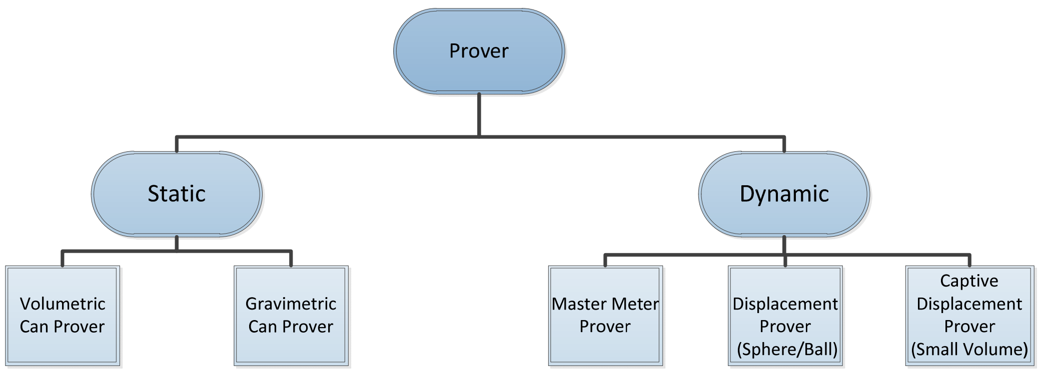

Figure 1. Equipment Type Classifications

<u>Key Components and General Operation:</u>
The **volumetric test measure tank prover** is covered in the API MPMS Chapter 4.4 and was the first product to gain acceptance in the industry for meter accuracy verification in the field. This device is mechanical in design and is the simplest to use and operate. The primary tank prover consists of a certified volume tank or test measure (sized by the required amount of fluid delivered in 1 minute at the actual maximum flow rate) with graduated neck and a gauge glass and scale (scale is designed for $\pm$ 0.5 percent of tank certified volume) on the top and possibly the bottom of the tank to measure the tank zero start and stop volume position respectively. There will be temperature measurement locations on an open or closed type system. On a closed tank system, pressure measurement is added as well as inlet/outlet flow connections and drain valve, vapor recovery or release system, overlapping tank side site glasses, and many other components as illustrated in API MPMS Chapter 4.3. When moving from a stationary tank prover to a portable system the additional components needed are a vehicle or trailer, leveling equipment, hoses and connectors, and possibly a small liquid pump-off system.
The use of a tank prover is simple in operation; the most important part is selecting the correct size tank for the meter flow rate(s) to be calibrated. Once all piping connections are established and tank is verified as empty the inlet flow to the prover begins and fills the tank to the appropriate level. When the tank has reached the upper neck gauge glass and the fill line falls within determined tank volume scales, the flow is stopped. The technician reads the scale for the exact gross volume measurement in the tank and this volume has a direct relationship with the registered volume of the meter under test. These values are then used to calculate a new meter factor. A verification proving is then required to assure that any changes applied had the desired result.

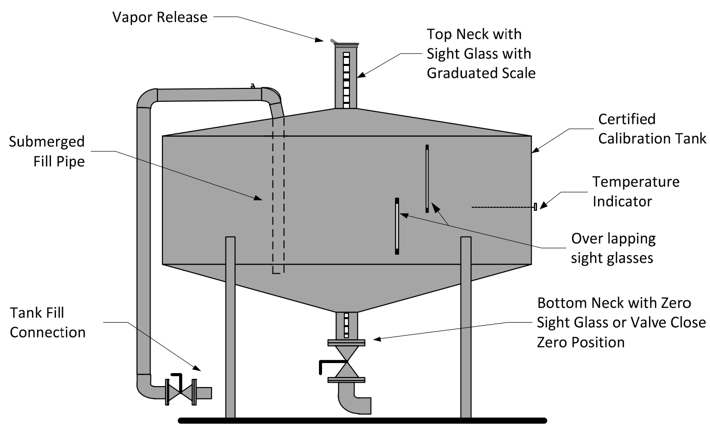

Figure 2. Components of Normal Tank-type Prover

Critical Characteristics of Tank Type Provers

- Using the one minute of flow rule for tank size, prover tank can become very large and difficult to maneuver and use
- The can needs to be drained after each proving – in some cases product will have to be pumped to a slop tank resulting in considerable product loss.-
- If used on a loading bay it can stop truck loading for long period of time.
- Particle or heavy viscous product build-up can cause volume changes
- Well maintained tanks require little maintenance costs.

The **gravimetric test measure tank prover** is accepted for use in meter verification but not approved by API as a proving device. When using a gravimetric tank prover, the most significant component is the certified weights used to calibrate the scale and the scale(s) itself. The scale is used to weigh the tank empty to establish tare weight, and also verify the weight of the product in the tank once a quantity is measured through the meter and into the scale tank. The volume amount is verified by the equipment mass weight on the scale. Once the weight of the product is determined, the product density must be verified and used to convert the mass measurement to a volumetric measurement for comparison to the meters registered volume.

Gravimetric test measure tank proving in a test lab environment is one way that displacement type prover's manufacturers use to verify the volume of the measurement area of each size prover. When completing a water draw certification for a displacement prover, the weighted amount is determined by the amount of fluid registered between detector switch one and detector switch two. Once the weight of the distilled water is found, the temperature and pressure of the water in the prover body is used to convert to a certified volume amount. (Refer to API MPMS Chapters, 4.9.4, Chapter 12.2.4).

Figure 3. ISO 17025 Certified Gravimetric Water Draw Test Stand – Flow MD – Phoenix, AZ

Critical Characteristics of Gravimetric Type Provers

- Scales and tank can become very large and difficult to maneuver and use.
- Scales is a mass device and requires precise temperature and density to convert to volume
- The can needs to be drained after each proving – in some cases product will have to be pumped to a slop tank resulting in considerable product loss.
- Normally used on water test verification or refined equipment.
- Particle or heavy viscous product build-up can cause volume changes
- Well maintained tanks require little maintenance costs.

The **master meter prover** is covered in the API MPMS Chapter 4.5 and has been used in the industry for many years. Master meter proving requires the use of a higher accuracy meter (preferable 10 times more accurate meter being verified) installed in series on the pipeline along with the meter being verified. There will be a pulse counter system that allows the user to gather flow information over a greater time intervals and allows the user to gather as many pulses as they desire. The master meter register volume is then compared with the test meter volume and a new meter factor will be calculated. A verification proving is then required to assure that any changes applied had the desired result.

Figure 4. Master Meter Cart Designs

Critical Characteristics of Master Meter Prover

- A proving device should be preferable be 10 times more accurate than the device being proved. Avoid using a equally or less-accuracy device to “prove” a similar, less-accuracy device;
- Measurement errors form normal operation of the master meter will be transferred to the test meter
- The Master Meter accuracy could be effected by liquid viscosity, flow rate, temperature or pressure;
- Master Meters are usually designed for a specific fluid type and can’t be used on a range of fluids

The **conventional pipe prover** (ball / sphere type) is covered in API MPMS Chapter 4, Section 2 and can be designed for unidirectional or bidirectional operation. The pipe prover was designed for all levels of flow, but gained the greatest acceptance in the industry in larger pipelines where other prover types were unable to handle the higher flow rates. Despite involving a much larger footprint than other types of provers, the pipe prover is very simple design. The criterion for a unidirectional pipe prover is a minimum sphere velocity of 1 foot /second and maximum sphere velocity of 5 feet/second. The bidirectional pipe prover design sphere velocity must be between 0.5 feet per second and 10 feet per second, but in either design the prover must allow for the counter to accumulate of 10,000 pulses between the two required detector switches. (Check API MPMS Chapter 4.2, Appendix B). Pipe provers come in multiple sizes and designs, flow rates, and sphere velocity calculations that affect the overall footprint of the individual device.

Figure 5. Different Ball Prover Configurations

The key components of a pipe prover are the U shaped smooth lined uniform circumference pipe, the four way diverter valve system, the inflatable prover ball or displacer sphere, the ball launching chamber(s), the two detector switches and a meter pulse generating proving counter.

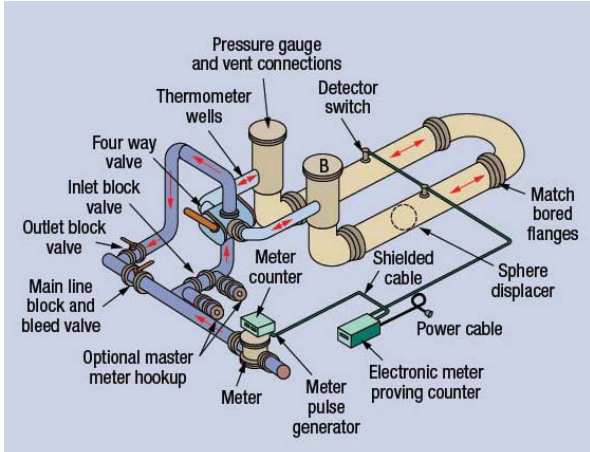

Figure 6. Ball Prover Components

Before the proving operation starts, a required proving flow rate must be established. The proving pass is started when the four way valve actuates to launch the prover sphere into the flow pipe. It then travels through the pre-run area until it reaches the u shape measuring section of the pipe. When the sphere contacts the first mechanically actuated detector switch, the counter is started and the sphere continues to travel until the second detector switch is activated, at which time the counter is stopped signaling a complete pass in a unidirectional prover. The sphere continues to travel until it reaches the other launch chamber where it remains until the start of the next proving pass. If bidirectional, the four way valve will again actuate to start the pass in the opposite direction and when concluded will be a single pass registration. The flow pulses accumulated from the test meter are then compared with the pulses generated from the accumulated volume between the detector switches on the prover. The proving passes are continued until sufficient passes are completed and the multiple pulse totals can be compared with sufficient repeatability to satisfy the requirements as specified in API MPMS Chapter 4.8, Chapter 9.3, and Chapter 13.2.

Critical Characteristics of Conventional Pipe Prover

- Ball provers requires launch and receive chambers and long pre-run distance;
- Possible high pressure drops with Ball Provers;
- More difficult calculations to correct for temperature and pressure;
- Appreciable uncertainties due to mechanically activated detection switches;
- Large in size and expensive to install.
- Sphere materials must be compatible with product, ball change with product change
- Appreciable uncertainties due to mechanically activated detection switches and detector switch might be sensible to vibrations;
- Difficult to maintain and service

The **Captive Displacement or Small Volume Prover** is a unidirectional device that is also covered in API MSMP Chapter 4.2. It has insufficient reference volume to accumulate 10,000 pulses in a single run and requires pulse interpolation software to calculate the 10,000 pulse requirement to satisfy a proving pass. One of the most significant design changes compared to a pipe prover was relocating the detector switches to the outside of the measurement pipe and installing them on a switch bar. This allows for higher quality switch activation and easier access for service. The most significant advantage of the design is the ability to verify meter accuracy faster over a larger flow range with an average1200 to 1 turndown and considerably reduced footprint for installation. The major components of the small volume prover (SVP) are the prover body, prover frame, piston assembly, optic switches, puller assembly, drive system, drive shaft, and controller. For the complete proving operation there is also a need for a flow computer or proving software that takes in raw data from the prover and meter under test and per API MSMP Chapter 12.2 requirements calculates all data and generates a proving report automatically.

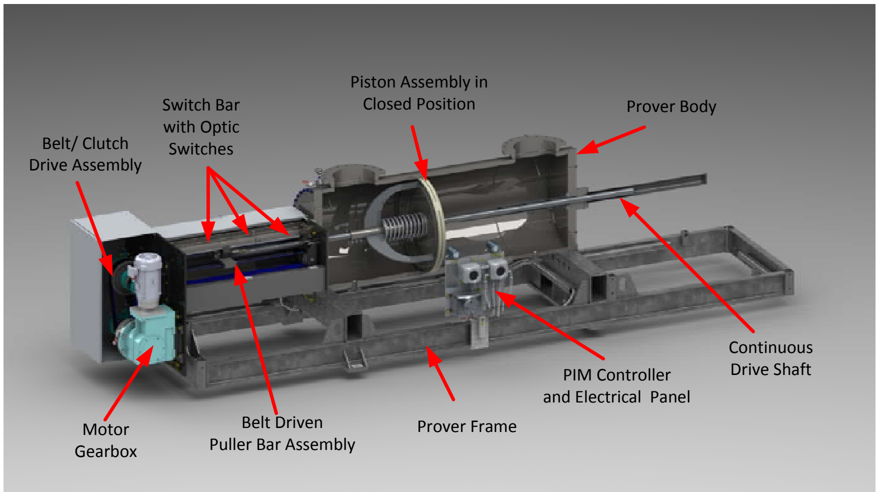

Figure 7. Flow MD SVP Components

The operation of the SVP is nearly fully automated. Once the valves are aligned to direct flow through the prover and the required flow rate is set, the flow computer sends a signal to the SVP controller to begin the proving. That signal will then start the drive system bringing the draw the piston back to the start pulling the piston shaft to the upstream position and in front of the first optical switch. Once the clutch releases the piston the flow pressure will close the piston and begin the travel through the certified measurement portion of the prover flow tube. The certified measurement for calibration occurs when the optic flag mounted on the external portion or the drive shaft, activates the first optical switch and continues the travel downstream until the second optical switch is contacted signaling the end of the first pass. Simultaneously, when the first optical switch is contacted, a signal is sent to the flow computer to start both the interpolated signal prover counter and the counter for the meter under test. This begins the pulse accumulation from the meter and the controller. When the second optical switch is activated a signal is sent stopping the pulse counters, signifying the end of the next pass. This process continues until the set quantities of required passes are complete. During this process the flow computer is receiving pressure and temperature information from transmitters installed downstream as well as the temperature of the switch bar on the prover and also upstream by the meter in the pipe line. Once the multiple pass information is processed it will be compared for sufficient repeatability to satisfy the requirements as specified in API MPMS Chapter 4, Section 8; Chapter 9.3; and Chapter 13.2. The API proving reports can then be generated automatically as required.

Critical Characteristics of Uni-Directional Captive Displacement Prover

- Can be used in situations where it is possible to collect less than 10,000 meter pulses in a prover pass, by utilising "Double Chronometry" or pulse interpolation.
- Designed with internal piston to displace the volume and externally mounted optical detector switches.
- Precise external optical switches are easily serviced.
- Small amount of liquid required for a volume water draw test.
- Piston and Poppet assemble is designed for fail safe operation not to disrupt flow.
- Prover allow for accurate measurement of flow meters with a wide variety of fluids. The repeatability of a prover will be better than 0.02% as stated in the API guidelines.
- Has a turndown ratio of 1200 to1 allowing for use for multiply size meters.
- SVP does not do any calculation itself, the pulse interpolation is completed in the flow computer or other type computing devices that is part of the proving system.

Pulse Interpolation

With this introduction of pulse interpolation and the use of multi-pass runs, both defined within API Standards,, has increase the ability for proving all size and types of meters using a SVP The Double Chronometry Pulse Interpolation is most widely used in the SVP, but is also used with the Conventional Ball or Pipe Prover with the 10,000 pulse counter requirement cannot be achieved

The first action begins with a signal from the upstream detector switch, starting clock one (ET1, displacer elapsed travel time), next clock two starts with the detection of the first complete pulse (ET2 for the elapsed time to measure whole pulses). At the same time the accumulation of pulses (WP, whole meter pulses) from the meter being tested is also started.

Clock one stops accumulating based on a signal from the downstream detector switch. Clock two stops accumulation based on the detection of the first whole pulse signal from the downstream detector switch which also stops the whole pulse accumulation. This method allows for the collection of (E_{T1}) elapsed travel time of displacer, (E_{T2}) elapsed time of whole pulse accumulation, (WP) whole pulse accumulation from meter and (D_V) which is the already known displaced or calibrated volume for the prover. Taking these measurements multiple times within required repeatability values allows for the calculation of the new K-Factor.

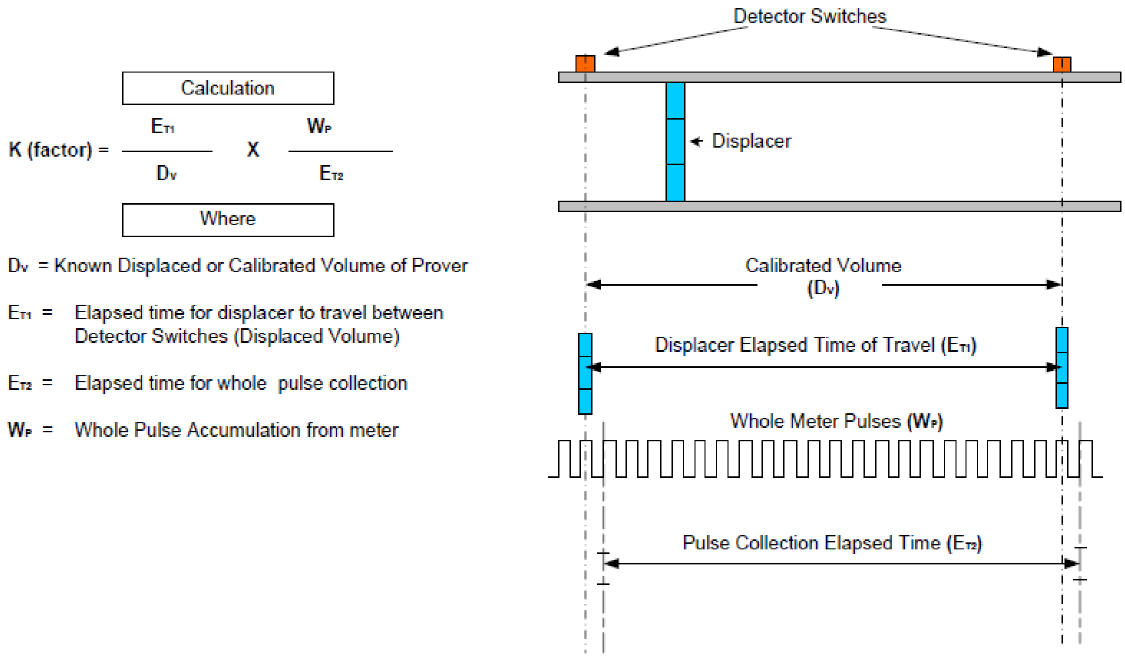

Figure 8. Double Chronometry Pulse Interpolation Formula and Diagram

Industry acceptance of multi-pass runs for proving allows for adjustment in repeatability limits while still meeting ± 0.0027% uncertainty helped tremendously in allowing for use of the SVP when using the newer technologies like Coriolis and Ultrasonic and their manufactured pulse signals. (API Chapter 4, Section 8, Appendix A and Chapter 12, Section 2, Part 3 address the issue of multi-pass uncertainty limits.)

All meter models and sizes can now be easily verified by the SVP to an acceptable repeatability value more efficiently and faster than using a bidirectional pipe/ball prover. Allowing pipeline operators the opportunity to make multiple proving passes while increasing the limits of repeatability while still maintaining the ± 0.027% uncertainty level required in the industry.

From API MPMS Chapter 4.8 Runs at proving repeatability to meet ± 0.00027 uncertainty of Meter Factor		
Proving Runs	Repeatability Limit	**Meter Factor Uncertainty**
3	0.02	0.00027
4	0.03	0.00027
5	0.05	0.00027
6	0.06	0.00027
7	0.08	0.00027
8	0.09	0.00027
9	0.10	0.00027
10	0.12	0.00027
11	0.13	0.00027
12	0.14	0.00027
13	0.15	0.00027
14	0.16	0.00027
15	0.17	0.00027
16	0.18	0.00027
17	0.19	0.00027
18	0.20	0.00027
19	0.21	0.00027
20	0.22	0.00027

Table 1. Pulse Average Table from API MPMS Chapter 4.8

Groups and Agencies that Govern the Proving Processes:

The American Petroleum Institute (API), International Organization of Legal Metrology (OIML), and National Institute of Standards and Technologies (NIST) oversee the meter proving process generally. There are global requirements and regional requirements to be aware of and the specific regulations or standards for each country, providence, state or city where measurement equipment and measurement verification devices are used must be taken into account. Noted below in the reference sections are documents that should be evaluated when proving meters and for the operation and design of verification equipment and systems.

Summary:

The important information in this paper is the best way to minimize losses and maximize profitability is periodic verification of meter accuracy and repeatability through the complete flow range. There are many options for using a proving device and all influences like accuracy, flow rates, measurement turndown, environment, installation and operational costs, local agency acceptance should be part of that decision. There are applications for every type of proving device and hopefully the information provided here has supplied guidance for help in making those decisions.

References:

American Petroleum Institute, “Manual of Petroleum Measurement Standards,” Chapter 4, “Proving Systems”, Section 1, “Introduction”, Section 2, “Displacement Provers”, Section 4, “Tank Provers”
Section 5, “Master-meter Provers”, Section 6, “Pulse Interpolation”, Section 7, “Field-standard Test Measures”, Section 8, “Operation of Proving Systems”Section 9, “Calibration of Provers”.

American Petroleum Institute, “Manual of Petroleum Measurement Standards Chapter 9—“Density Determination”, Section 3—“Standard Test Method for Density, Relative Density, and API Gravity of Crude Petroleum and Liquid Petroleum Products by Thermohydrometer Method”

American Petroleum Institute, “Manual of Petroleum Measurement Standards Chapter” 12 “Calculation of Petroleum Quantities”, Section 2—“Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors “, Part 4—Calculation of Base Prover Volumes by the Waterdraw Method”.

American Petroleum Institute, “Manual of Petroleum Measurement Standards”, Chapter 13 –Statistical Aspects of measuring and Sampling”, Section 2—“Methods of Evaluating Meter Proving Data.”

International Organization of Legal Metrology, OIML-R119,” Pipe provers for testing measuring systems for liquids other than water” 1996, www.oiml.org

Lee, Diane G., “Series 1 – Small Volume Provers: Identification, Terminology and Definitions,” March 2005; www.nist.gov/owm.

Lee, Diane G., “Part 2 – Small Volume Provers: History Design and Operation,” June 2005; www.nist.gov/owm.

Lee, Diane G., “Part 3 – Small Volume Provers: Mathematical Determination of Meter Performance Using SVPs,” August 2005; www.nist.gov/owm.

Lee, Diane G., “Small Volume Provers (SVP) Proving Reports ‘March 2006”; www.nist.gov/owm.

APLJaK Ventures Kelowna, BC, Canada, Website “Volumetric Calibration”

Bos, Rudd, “Liquid Flow Provers, Operations of Liquid Flow Provers” May 2009