

Fundamentals of Meter Provers and Proving Methods

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1. Introduction: This paper will verify the history, requirements, and operation of all Provers accepted for liquid pipeline meter uncertainty verification in the Liquid Oil/Gas Industry. It will continue with an explanation of the different proving methods accepted by the industry and approval groups. This document will provide the reader with information on meter types and the flow volumes that can be used with Can Provers, Ball Provers, and Unidirectional Compact Provers (UCDPs), and will examine the opportunities for using a UCDP as a mass prover. It will also provide the information for field verification of provers, known as a water draw.

2. What is a meter prover?

A meter prover is a device used to verify flow meter uncertainty 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 the net standard volume of a receipt or delivery of liquids.

$$\frac{\text{Prover Test Known Volume}}{\text{Volume Measured by Meter}} = \text{New Meter Factor}$$

Figure 2: Meter Factor Formula

3 Why do companies prove flow meters?

The purpose of meter verification or meter proving is to provide an accurate measurement, which minimizes losses and maximizes 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, it becomes clear how much money there is involved:

- An 8-inch crude line delivers product to a Refinery at a flow rate of 2,150 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 at 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.

4. Where does a Prover Device fall within the Agency Approvals?

Within API MPMS Chapter 4, there is an overview of the Hierarchy in proving products.

Liquid metering systems designed and operated in conformance with **API's Manual of Petroleum Measurement Standards** typically have one or more of the following levels of hierarchy as shown below.

- **Level 1.** Primary standards involve mass, volume, and/or density standards developed and/or maintained by National Institute of Standards and Technology (NIST) and/or other national laboratories to

calibrate secondary working standards.

- **Level 2.** Secondary working standards include mass, volume, density, and/or weighing systems maintained by NIST and/or other national laboratories to calibrate field transfer standards conforming to Chapter 4.7. Secondary working standards may also be maintained by state and other certified metrology laboratories to calibrate field transfer standards. These additional secondary working standards, however, increase uncertainty in the final custody transfer quantities.
- **Level 3.** Field transfer standards conforming to API MPMS Chapter 4.7 are devices used to calibrate meter provers in compliance to API MPMS Chapters 4.2, 4.3, and 4.4.
- **Level 4.** Meter provers in compliance with Chapter 4 can be used to determine meter factors that correct the indicated volumes of meters.

world of Captive displacement Provers, the Volume Can and the Scale Can Provers are used for Volumetric and Gravimetric Prover verification, respectively. Certification of a Prover is noted in the API MPMS Chapter 4 and OIML R119 documents, and is required every 1 to 5 years, depending on the type of service they're used for.

When a Master Meter is used to certify the volume of a ball prover, the UCDP becomes, in most cases, a critical part of the Pipe/Ball Prove field certification as noted in Figure 13.

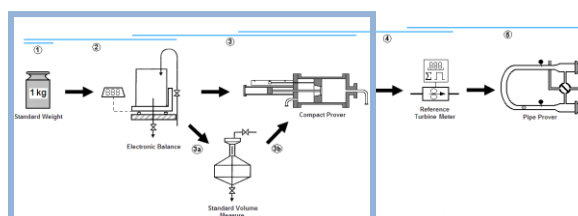


Figure 13: Field Water Draw for UCDP in a 3 Step Process, or for Ball Prover in 5 Step Process.

Traceability Pyramid of Standards

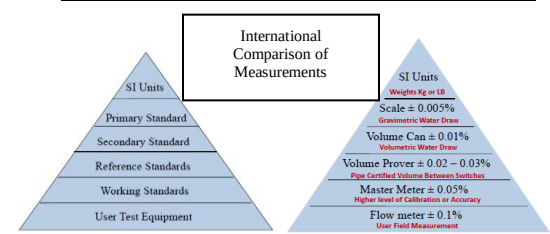


Figure 12: Pyramids of Traceability for Working and Operational Standards.

These traceability standards (Listed in Figure 12) can be used for all liquid measurements in the global market. Starting with the meter on the bottom to the SI weights on the top. Each level requires a minimum of 2x better capability of certification.

The Captive Displacement Volume Prover lies in the middle of the Traceability Pyramids illustrated above. What this means is that the prover devices that have higher uncertainty can and are used to verify each other. In the

Although capable of being certified by a volumetric can for the water draw, one of the greatest advantages of the UCDP is the ability to be field certified gravimetrically with the use of an electronic, high-precision balance (scale). The largest UCDP designed at this time has a 5 BBL certified volume, which can be gravimetric water drawn using a scale and a tank that can handle a weight of 1500 lbs. Manufacturers of UCDP have recognized the importance of accurate volume calibrations and have employed the gravimetric method in their final acceptance testing for years. According to an ISHM Paper (Reference 13 below) that made the comparison, the gravimetric method has a significant improvement (decrease in value) in uncertainty compared to volumetric water draws. The results of the comparison show an improvement in uncertainty greater than an order of magnitude (a factor of 10) for the Gravimetric Method.

5. 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 indicated amount of the meter under test. For static proving, the proving is performed in a stop-to-stop manner and will require interruption of the flow process to perform the meter factor verification. This is normally an open system, but a closed system is often required when testing with a volatile product.

In the **dynamic** scenario, the fluid remains in a closed system whereby the pulse registration of the meter under test and the certified volume of the prover are compared directly. There is no interruption of the normal flow process during this verification of the meter factor.

6. 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 best product available for volume measurement verification and has been around since the turn of the 20th century. The volume tank prover may be used for the calibration of liquid flow meters, but is also approved for performing a volumetric water draw calibration of displacement provers per API MPMS Chapter 4.9. The accuracy uncertainty is specified per tank volume size.

Note: Tanks over 100 gallons have an uncertainty of +/- 0.01% or less per NIST

uncertainty analysis; tanks 100 gallons or less range from +/- 0.015% for 100-gallon cans to 0.3% for 1-gallon cans.

The **master meter prover** solution has many possible applications for proving, and are noted in 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 from all local or regional agencies. The required verification of the master meter's accuracy must be established by using a displacement-type or a volumetric tank prover. This should be completed before the start of any meter verification when product characteristics (products, temperature, pressure, density, viscosity) have changed since the last master meter proving.

The petroleum industry and American Petroleum Institute (API) have accepted the use of **volume displacement provers** in two categories:

- a) The **conventional pipe prover**: A displacement prover that generally contains sufficient reference volume to allow for the collection of 10,000 whole pulses from the meter in a single pass, and
- b) The **UDCDP**: A displacement prover that generally contains insufficient reference volume for the collection of 10,000 whole pulses from the meter in a single pass and requires the use of pulse interpolation software by the flow computer.

In both cases, it will require multiple runs for a proving session and to establish a new meter factor for the meter being tested. 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-1970s, after the acceptance of the double chronometry pulse interpolation method as defined and described in API MPMS Chapter 4.6.

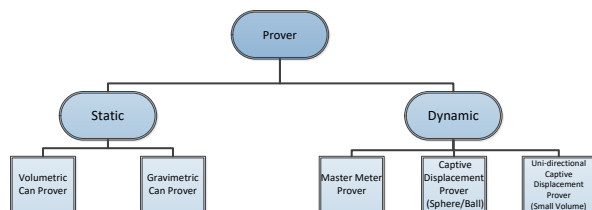


Figure 3: The chart above depicts the classification of each equipment type.

When discussing displacement provers, it is important to understand the difference between a pass and a run. These terms are often used interchangeably in some situations, but can cause confusion in other applications. A PASS is the single movement of the prover detector between 2 switches. In a unidirectional pipe prover a pass is a run. In a bidirectional pipe prover a run is the total of an out pass and a back pass of the displacer. For UDCP provers, especially with specific meter types, a common practice is to average multiple passes to create multipass runs. This allows for the accumulation of a larger representative volume.

7. Key Components and General Operation of Products used as Provers:

7.1 The Volumetric Tank/Can Prover is covered in 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 ± 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 a drain valve, vapor recovery or release system, overlapping tank side sight glasses, and many other components, as illustrated in API MPMS Chapter 4.4. 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 the tank is verified as empty, the inlet flow to the prover begins and fills the tank to the appropriate level. When the tank volume reaches the upper neck gauge glass and the fill line falls within the 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 the test meter's new meter factor. If changes are made, a verification proving is then required to ensure that any changes applied had the desired result.

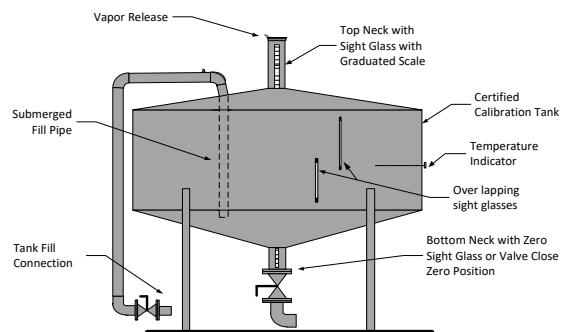


Figure 4: Components in a standard Tank Prover

Critical Characteristics of Tank Type Provers

- Require stop-to-stop proving due to the filling and draining of the can.
- Using the one-minute of flow rule for determining the tank size, prover tanks 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 operations for long period of time.
- Particle or heavy viscous product build-up can cause volume changes.
- Well-maintained tanks require little maintenance costs.

7.2 The Master Meter Proving solution has been applied for years, and the operational requirements are covered in API MPMS Chapter 4.5. Master meter proving requires the use of a higher accuracy meter (verified to a higher accuracy level than the meter under test) 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 greater time intervals and allows the user to gather as many pulses as they desire. The master meter volume registered is then compared with the test meter volume register, and a new meter factor can be calculated from the comparative totals. A second verification of the master meter proving is required to ensure that any changes applied had the desired result.



Figure 6: Master Meter Test Cart

Critical Characteristics of Master Meter Prover

- A proving device should preferably be 10 times more accurate than the device being proved. Avoid using an equally or less accurate device to “prove” a similar, less accurate device.
- Measurement errors from normal operation of the master meter will be transferred to the test meter

- The Master Meter accuracy could be affected 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
- Master meters are a great option for comparison and verification between meter provings. They can also be very beneficial in identifying metering and system issues.

7.3 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 has a very simple design. The criterion for a unidirectional pipe prover is a minimum sphere velocity of 1 foot per second and a maximum sphere velocity of 5 feet per 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 in most cases should allow for the counter to accumulate 10,000 pulses between the two 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 7: Examples of Pipe/Ball Provers

The key components of a pipe prover are the smooth-lined uniform circumference pipe, the inflatable prover ball or displacer sphere, the ball launching chamber(s), the two detector switches, and a meter pulse-

generating proving counter. For bidirectional ball provers, a four-way diverter valve will be required to facilitate bidirectional operation. If the ball prover is unidirectional, an interchange for recycling the ball between runs will be required.

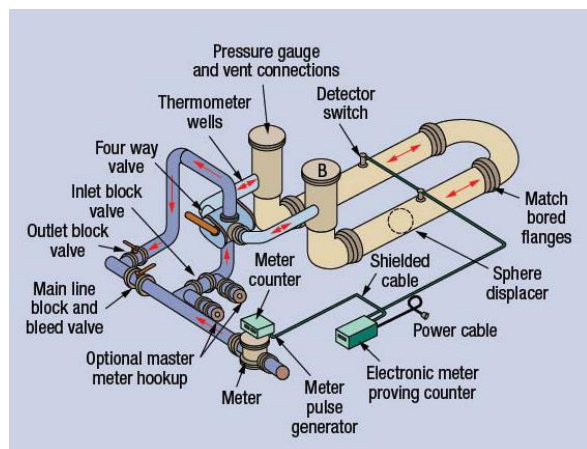


Figure 8: Standard components in Pipe/Ball Prover

Before the proving operation starts, a required proving flow rate must be established. The proving pass starts when the launch command is sent to the prover and the prover sphere is cycled into the flow pipe. The sphere then travels through the pre-run area until it reaches the measurement 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 launch chamber, where it remains until the start of the next proving pass. If bidirectional, the four-way valve will actuate to start the pass in the opposite direction, and when concluded, a single pass will be completed and registered. The flow pulses accumulated from the test meter are then compared with the known accumulated volume between the detector switches on the prover. The proving runs are continued until sufficient runs 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 Provers

- Ball provers require launch and receive chambers and long pre-run distance.
- Possible high-pressure drops.
- Calculations must be performed to correct for temperature and pressure.
- Considerable uncertainty added due to mechanically activated detection switches.
- Large in size and expensive to install.
- Sphere materials must be compatible with the product. Ball changes with product change.
- Difficult to maintain and service

7.4 The Uni-directional Captive Displacement Prover or Small Volume Prover

is a device that is also covered in API MPMS Chapter 4.2. This type of prover uses pulse interpolation to allow for the collection of fewer than 10,000 pulses in a single run. 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 hardware, a much faster activation of the switch, as well as 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 a 1200 to 1 turndown and considerably reduced footprint for installation. The major components of the UCDP are the prover body, prover frame, piston assembly, optical 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 capable of performing the double chronometry calculations required for pulse interpolation. The flow computer will take in raw data from the prover and meter under test, and per API MPMS Chapter 12.2 requirements, calculate all data to generate a proving report automatically.

Another tremendous advantage UCDPs have when used for dry LPGs meter proving

is the low-friction seals that allow for smooth operation during proving. With the LPGs, the Pipe/Ball Prover is susceptible to squealing and lunges during the displacement of the ball due to minimal to no lubrication capabilities of the product.

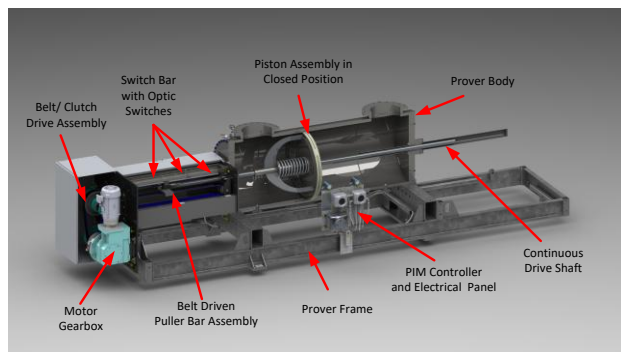


Figure 9: Standard Components for Flow MD UCDP

Once the valves are aligned to direct flow through the prover and the required flow rate is set, the flow computer outputs a signal to the UCDP controller to begin the proving run.

That signal engages the drive system, drawing the piston shaft to the upstream position in front of the first optical switch. Once the drive system releases the piston, the product flow velocity will close the poppet valve in the piston, and the product will push the piston downstream through the certified measurement section of the prover's flow tube.

The certified measurement for calibration begins when the optic flag mounted on the external portion of the drive shaft activates the first optical switch, then it continues to travel downstream until the second optical switch is activated, signaling the end of the first pass.

Simultaneously, when the first optical switch is contacted, a signal is transmitted to the flow computer to start the interpolated signal prover counter and the counter for the meter under test. This begins the pulse accumulation from the meter and the registration of both clock cycles required for double chronometry. When the second optical switch is activated, a signal is sent stopping the pulse counters, signifying the

end of the pass. This process continues until the set quantities of required passes and runs are complete. During each pass of proving, the flow computer is receiving pressure and temperature information from transmitters installed on the prover tube as well as the temperature of the switch bar on the prover. The flow computer also receives pressure and temperature readings from the meter being proven. Once multiple runs are processed, the results 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

- Collect less than 10,000 meter pulses in a prover pass, by utilising "Double Chronometry" or pulse interpolation.
- Designed with an 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 assembly is designed for fail-safe operation, not to disrupt flow.
- Prover allows 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 to 1, allowing for use on multiple size meters.
- UCDP pulse interpolation is completed in the flow computer.

8. Water Draw Calibration Methods

Volumetric and gravimetric calibration are both acceptable for calibrating provers. Calibration is the process of using traceable standards to assure the certified volume of the prover.

8.1 The Volumetric Water Draw Method

In the volumetric calibration of the prover, one or more certified prover cans are used to certify the prover. This process is performed with water. To accomplish this, the cans must be filled to “wet down.” This is an initial fill performed to assure consistent clingage on the internal surfaces of the prover cans. All cans should be drained, consistent to how they were originally calibrated.

When the calibration is performed, electronic means for diverting the flow from a recirculation system to begin filling the can(s) are needed.

As each can is filled, it is imperative that the flow can be stopped when the liquid level in the tank reaches the graduated neck of the certified can to allow for a proper reading.

It is desirable to use as few cans as possible to lower the uncertainty of the water draw.

As each can is filled, a temperature reading will need to be taken from the can to correct for water volume and the steel correction for the can.

For this process, the prover is launched and when the first detector is activated, the flow is diverted from the recirculation/waste system to the certified cans. Multiple cans can be filled as the prover displacer moves between switches. Temperature and pressure of the prover will need to be recorded, as well as the volume of each can and the can temperatures.

When the prover displacer activates the second detector switch, the flow is diverted from the certified cans back to the recirculation/waste system.

The prover is then prepared for the next certification run.

8.2 The Gravimetric Water Draw Method.

When performing a prover certification, the most significant components are 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 water in the tank once a prover certification pass is completed into the scale tank. The volume amount is calculated by the mass indicated on the scale.

Once the mass of the water is determined, the product density must be verified and used to convert the mass measurement to a volumetric measurement to calculate the prover volume.

Gravimetric water draw calibration in a lab environment is one method that UCDP prover manufacturers use to verify the volume of the measurement section 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, and 12.2.4).



Figure 5: ISO 17025 certified gravimetric water draw test stand – Flow MD – Phoenix, AZ

9. UDCDP Designed for Mass Proving

As the use of Coriolis Meters (designed to measure mass first and density second) continues to expand in the liquid oil and gas market, the required volumetric proving can become a challenge.

First, Coriolis Meters have very little influence for measuring mass. The

movement of the fluid inside the tube causes the time phase shift from the inlet to the outlet electronic measurement coils, which has a direct relationship to mass flow.

The density measurement is derived from the vibrational frequency of the tube. Changes in weight of the tube will change the density of the output.

When using the Coriolis meter for volume measurement, the standard formula for calculation of volume = mass / density is utilized.

If there is product buildup on the walls of the tubes (this buildup usually has a different density than the product in liquid state inside the tube), the different densities of both phases during flow may cause errors in the volume output.

This is where the UCDP with the option for an installed Densitometer and a Pycnometer can be used as a complete Mass Prover solution.

This system allows for the verification of all of the parameters of the measurement uncertainty on a Coriolis meter. Also note the temperature and pressure of the measurement is verified as part of the required parameters as with all proving calculations.



Figure 11: Standard Mass prover design

10. 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.

11. Summary

There was a great deal of information provided in this paper. The idea was to supply enough information that would substantiate the use of a UCDP as an acceptable and viable proving device from both an economic and qualitative perspective for the liquid Oil and Gas Industry.

As the industry changes from the original technology (Turbine and PD) to the newer technologies (Coriolis and Ultrasonic) for metering liquid products, the UCDP will continue to be the operative choice for the future. There are many options for using a proving device, and all influences like accuracy, flow rates, measurement turndown, environment, installation and operational costs, and 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 to help make those decisions.

References:

- 1) 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".
- 2) 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"
- 3) 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".
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- 13) 27th International North Sea Flow Measurement Workshop 20 – 23 October 2009, Tønsberg, Norway--Realistic Pipe Prover Volume Uncertainty--Paul Martin, IMASS (formerly Smith Rea Energy Limited).
- 14) ISHM 2013 Paper 4200 The Uncertainty of a Water draw Calibration vs. Gravimetric Calibration on Small Volume Provers --- Gary Cohrs, Flow Management Devices