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CALIBRATION OF LIQUID PROVERS

Class 4020

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INTRODUCTION:

A meter prover is used to calibrate custody transfer meters to establish a meter factor. The volume that passes through the meter is compared to the prover volume during the time taken for a sphere or piston to pass between two detector switches. The prover volume must be accurately determined by a calibration procedure known as the "Water Draw" method.

CALIBRATION EQUIPMENT:

Step one of obtaining a correct waterdraw is knowing your equipment and how it functions. The test measure standards may be made of carbon steel or stainless steel. If they are made of carbon steel, they should be internally coated to resist the effects of commercial solvents, petroleum products and water. Non-invertible standards must be equipped with a fixed anti-swirl plate. Test measures can be calibrated either "to contain" or "to deliver". "To contain" means that the measure has to be completely dried out before each fill (dry volume). "To deliver" means that the measure will be allowed to drain for a specified time after cessation of the main flow of water. API Petroleum Measurements Manual, Chapter Four states that all non-invertible test measures shall be drained for 30 seconds from the cessation of main flow and the drain valve is then closed. The test measure is now ready for use in the "to deliver" mode. All invertible test measures shall be drained at a specified angle (e.g., 70 degrees) for 10 seconds from cessation of main flow when inverted. After 10 seconds, it is turned back upright and it is ready for use in the "to deliver" mode. "To deliver" standards are used for waterdraw calibrations as test measures have to be used more than once in a run on large volume provers. YOU MUST USE THE SAME PROCEDURE ON SUBSEQUENT CALIBRATIONS AS WAS USED TO CALIBRATE YOUR MEASURES.

Before 1997, all test measures were calibrated by the volumetric transfer method. The volumetric transfer method would be:

- Fill NIST test measure
- Take temperature and scale reading and record
- Drain NIST test measure standard into the test measure that is being certified by using described draining method
- Take scale reading and temperature and record
- Drain test measure that is being certified using described draining method
- Repeat the above procedure a second time
- The two runs would be averaged to establish the volume of the test measure being certified

From 1997 forward, test measures have been calibrated by the gravimetric weighing method. The gravimetric weighing method procedure is:

- Establish empty weight
- Fill test measure
- Weigh full measure to establish "to contain" volume
- Observe temperature and scale reading and record
- Drain for described amount of time
- Weigh test measure in its wetted mode
- Fill, weigh, drain and weigh four more times to average all five runs and establish the volume at a 95% confidence level

When reviewing NIST certificates for the test measures you will see that the test measure was leveled using attached levels before scale reading is determined. Scale reading is then determined by the intersection of the horizontal plane, tangent to the bottom of the gauge meniscus, with the graduated scale. The test measure delivers ___ U.S. gallons at 60 degree F. when drained for the specified drain time. A separate calibration run is conducted on the top neck of the test measure to establish volume increments of the scale. The certificate will normally show the manufacturer, the owner, the NIST number, the nominal capacity, the actual capacity in cubic inches and U.S. gallons, and whether it was calibrated “to contain” or “to deliver”. Each standard shall bear, in a conspicuous place, the manufacturer, the nominal value and a serial or identification number. The material from which it is constructed shall be shown, together with its cubical co-efficient of thermal expansion per degree C or F.

THERMOMETERS:

Thermometers shall be calibrated once a year, with a certified thermometer that is traceable to NIST, and be readable and accurate to .1 of a degree increments. Normally two are used during a calibration, one at the outlet waterdraw connection and one for test measure temperatures.

PRESSURE GAUGE:

The pressure gauge should be calibrated once a year and 1 pound increments with accuracy to the same. It should be downstream of the prover and is generally located on the calibration unit manifold for traceability and accuracy purposes.

WATER:

The second step for a good calibration is to obtain good clean potable water, virtually free of foreign particles and free of air. It has to be in the temperature range of 33 degree F to 104 degree F.

SPHERE:

The next step is the sphere. Normal procedure is to fill the sphere with a 50% mixture of glycol or anti-freeze and water to prevent freezing. When sizing a sphere for a waterdraw it is recommended to check the previous waterdraw data to see what the sphere had been sized to, if the sphere had been sized an excessive amount check the notes in the waterdraw data to see why it had been oversized. If there is no data available it is recommended to size the sphere to 3% over the inside diameter of the prover. Check the sphere for air. It is very important to purge all of the air out of the sphere during the sizing process. It should be checked for 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 (1%) 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(Appendix A) will verify sphere roundness. Manufacturing tolerances for new spheres may be up to 1.5%. Lubricate with a thin layer of STP, grease or equivalent before loading sphere into the prover. The lubricant will ensure smooth operation of the sphere as water has no lubricity. If you have to oversize the sphere more than 5% to affect the capillary seal, the prover should be thoroughly inspected for debris, corrosion or anything that could affect a seal. Oversizing the sphere past 5 to 6% can cause various problems such as launching and repeatability

SWITCHES:

Prior to the waterdraw calibration, the detector switches should be removed, cleaned and inspected for wear. Any worn parts should be replaced. After reassembling the detector switches, check for smooth operation and accurate repeatability. If there is any doubt about their repeatability, you should consider replacing them before the calibration.

PROCEDURE:

Fill the prover and the calibration system with clean, potable water, using a 60 gpm circulating pump or larger to move the sphere from side to side to flush thoroughly and eliminate any air in the system. This also allows the water and the material in the prover system to reach a common stabilized temperature. All vent valves, drain valves, flanges and the 4-way diverter valve should be visually inspected for leakage. Pressure gauge on 4-way valve should be removed and opened to the atmosphere. Now move the sphere to the No. 1 detector switch, stopping it there by means of normally open solenoid valve attached to the detector switch. While approaching the first switch on the solenoid valve, you read and record the prover pressure. After the solenoid valve closes, manually close the valve downstream of the solenoid. Open the fill line valve to the first test measure to be used in the calibration. During the first third of the run, after the prover temperature has reached stabilization, read and record the prover temperature. Fill the required number of standards to move the sphere to the No. 2 detector switch stopping it there with a solenoid valve again. Record the scale reading and the temperature of each standard. Each standard has to be corrected for the thermal expansion due to temperature, as well as corrected back to 60 degrees as per API Petroleum Measurement Manual, Chapter 11.4.1. Each pass will be totaled after each standard has been corrected for temperature and then the total shall be corrected for hoop expansion and water compressibility as per API Petroleum Measurement Manual 12.2.4. Repeat procedures in the opposite direction through the prover. This constitutes a round trip in a bi-directional prover. According to API procedures, you make a second round trip using the same procedures but changing the rate by at least 25%. You then make a third round trip at the first run rate. API requires a minimum of 3 round trips (it can be more) that tie within $\pm$.02 of 1% after corrections to have a certified calibration. All left to right runs as well as the right to left runs must also tie within the .02 of 1% criteria. If agreed to by all parties involved, the fast-slow-fast procedure can be waived as long as you have a round trip at a reduced or different rate.

CALCULATION:

Calculation of prover volumes by the waterdraw method shall conform to Chapter 11.4.1-Table 1(Appendix B) for correction factor discrimination levels.

The actual volume of each test measure is the stated volume at the o mark $\pm$ the scale reading.

The temperature correction factor (CTL) based on the effect of temperature on the density of water has, in the past, been determined by the internationally accepted work of Wagenbreth and Blanke (API MPMS 11.2.3, 1984). The National Institute of Standards and Technology, as well as API, is now using the new equation proposed by Patterson and Morris as stated in Chapter 11.4.1, (Appendix "C") of this chapter is a predetermined table of representative density values in full degrees from 33 degree F (0.6 degree C) to 104 degree F (40.0 degree C). Prover and measure temperatures between full degrees have to be interpolated before being inserted into the formula. (Appendix D)

The metal correction factor (CTS) is based on the coefficient of expansion of the metal in the prover and measure (Appendix E). The formula for this is:

$$\frac{1+ (\text{TM}-60^{\circ}\text{F})\ \text{coefficient of expansion}}{1 + (\text{TP} - 60^{\circ}\text{F})\ \text{coefficient of expansion}}$$

You then multiply the actual quantity x CTL x CTS to get the temperature corrected volume of each measure. Then you total all the measures used to get quantity of each pass.

Because you are pressurizing the prover to displace the switch to switch volume into atmospheric test measures, you must correct for hoop expansion and water compressibility.

Hoop expansion (CPS) =

1+ (Prover Pressure x Pipe ID ÷ Modulus of elasticity x WT)

Water Compressibility =

1÷ (1-Compressibility of water x Pressure)

Divide the temperature corrected volume of each pass by CPS by CPL to get the corrected volume for each pass.

CONCLUSION:

You then average three round trips and convert the net cubic inches to either U.S. gallons or barrels and you have established the prover volume at 60 degree and atmospheric pressure.

REFERENCES:

API MPMS CHAPTERS
11.2.3
11.4.1
4.9.2
12.2.4

APPENDIX A

Examples of Sphere Ovality Verification:
A 6-inch sphere that is considered to be round, with a nominal diameter of 6.065 inches would be expected to have a diameter variation no greater than 1/16 inch and a circumference variation no greater than 3/16 inch. Alternatively, a 30-inch sphere with a nominal diameter of 29.250 inches would be expected to have a diameter variation no greater than 9/32 inch and a circumference variation no greater than 29/32 inch. 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	1/16	3/16
7.981	3/32	1/4
10.020	3/32	5/16
12.000	1/8	3/8
13.250	1/8	13/32
15.250	5/32	15/32
17.250	3/16	17/32
19.250	3/16	19/32
21.250	7/32	21/32
23.250	7/32	23/32
25.250	1/4	25/32
27.250	9/32	27/32
29.250	9/32	29/32
35.000	11/32	1-3/32
41.000	13/32	1-9/32
47.000	15/32	1-15/32

APPENDIX B

In many cases the number of decimal places that are to be used is influenced by the source of the data itself. For example, if a container's capacity table is calibrated to the nearest whole barrel, then all subsequent barrel values should be rounded accordingly. Furthermore, calculation standards such a *MPMS* Chapter 12 will specify rounding for each unique application. However, in those cases where there are no other limiting factors, the operator should be guided by Table 1.

Each calculated density shall always be rounded off in one step to three places past the decimal and not rounded in two or more successive steps. Water Volume Correction Factors are rounded to six places past the decimal. When the figure to the right of the last place to be retained is less than 5, the figure in the last place retained should be unchanged.

Table 1 – Significant Digits

Units	No. of Decimals
Gallons	xxxxx.xx
Barrels	xxx.xx
Cubic Meters	xxx.xxx
Cubic Inches	xxxxx.xxxx
Pounds	xxx.0
Milliliters	xxxxxx.xxx
Liters	xxx.0
Kilograms	xxx.0
VCF	x.xxxxxx
Density kg/m³	xxx.xxx
Density lb/gal	xx.xxx
Relative density	x.xxxx
Temperature ºF	xxx.x
Temperature ºC	xxx.x5
C_{pw}	x.xxxxxx

APPENDIX C

APPENDIX A –REPRESENTATIVE DENSITY VALUES

ºF	ºC	kg/m³	ºF	ºC	kg/m³
33	0.6	999.878	69	20.6	998.089
34	1.1	999.907	70	21.1	997.979
35	1.7	999.930	71	21.7	997.847
36	2.2	999.949	72	22.2	997.721
37	2.8	999.962	73	22.8	997.592
38	3.3	999.970	74	23.3	997.460
39	3.9	999.974	75	23.9	997.325
40	4.4	999.972	76	24.4	997.187
41	5.0	999.965	77	25.0	997.046
42	5.6	999.954	78	25.6	996.902
43	6.1	999.938	79	26.1	996.755
44	6.7	999.918	80	26.7	996.605
45	7.2	999.893	81	27.2	996.453
46	7.8	999.863	82	27.8	996.297
47	8.3	999.829	83	28.3	996.139
48	8.9	999.791	84	28.9	995.978
49	9.4	999.748	85	29.4	995.814
50	10.0	999.702	86	30.0	995.648
51	10.6	999.651	87	30.6	995.479
52	11.1	999.596	88	31.1	995.307
53	11.7	999.537	89	31.7	995.133
54	12.2	999.474	90	32.2	994.956
55	12.8	999.407	91	32.8	994.776
56	13.3	999.336	92	33.3	994.594
57	13.9	999.262	93	33.9	994.409
58	14.4	999.184	94	34.4	994.222
59	15.0	999.102	95	35.0	994.032
60	15.6	999.016	96	35.6	993.840
61	16.1	998.927	97	36.1	993.645
62	16.7	998.834	98	36.7	993.448
63	17.2	998.738	99	37.2	993.249
64	17.8	998.638	100	37.8	993.047
65	18.3	998.535	101	38.3	992.842
66	18.9	998.429	102	38.9	992.635
67	19.4	998.319	103	39.4	992.426
68	20.0	998.206	104	40.0	992.215

APPENDIX D

7 Examples

The following examples are for illustration purposes only. The relevant API *MPMS* chapters (4.9.2, 12.2.4, etc.) govern use and rounding for specific applications.

7.1 PROVER VOLUME, MEASURE TEMPERATURE HIGHER THAN PROVER TEMPERATURE (USC UNITS)

Problem: During a waterdraw, the water in a prover at 80.7ºF is transferred into a test measure volume of 11,551.50 cubic in. at 83.0ºF. What is the volume of the prover at 80.7ºF?

Solution: Use equation (2) to separately calculate the water densities P_{mt} and P_{pt}:

$$P_{mt} = 996.139 \text{ kg/m}^3$$

$$P_{pt} = 996.499 \text{ kg/m}^3$$

Their ratio is:

$$\frac{P_{mt}}{P_{pt}} = 0.999639$$

From equation (6), the prover volume is calculated to be (rounded to the same number of decimal places as the test measure):

$$V_p = V_m * \frac{P_{mt}}{P_{pt}} = 11{,}547.3299 \text{ cubic in @ } 80.7ºF$$

7.2 PROVER VOLUME, MEASURE TEMPERATURE LOWER THAN PROVER TEMPERATURE (USC UNITS)

Problem: During a waterdraw, the water in a prover at 83.0ºF is transferred into a test measure volume of 11,551.50 cubic in. at 80.7ºF. What is the volume of the prover at 83.0ºF?

Solution: Use equation (2) to separately calculate the water densities P_{mt} and P_{pt}:

$$P_{mt} = 996.499 \text{ kg/m}^3$$

$$P_{pt} = 996.139 \text{ kg/m}^3$$

Their ratio is:

$$\frac{P_{mt}}{P_{pt}} = 1.000361$$

From equation (6), the prover volume is calculated to be (rounded to the same number of decimal places as the test measure):

$$V_p = V_m * \frac{P_{mt}}{P_{pt}} \; 11{,}555.6701 \text{ cubic in @ } 83.0ºF$$

APPENDIX E

Correction Factors for Material Differences of Prover and NBS Cans
and/or a Temperature Difference of 3º F or Greater Between the Prover and NBS Cans

When the prover pipe is made from carbon steel and the NBS can is made from stainless steel and/or the temperature difference between the prover and the NBS cans is 3º F or greater, a correction for expansion must be made as follows:

Factor to be Applied to can Volume =

$$\frac{\text{CTS of Measure}}{\text{CTS of Prover}} = \frac{1 + (\text{Temp. measure-60})\ \text{Cubic Expansion Coefficient}}{1 + (\text{Temp. Prover-60})\ \text{Cubic Expansion Coefficient}}$$

Example: Mild Steel Prover - 65ºF
Mild Steel NBS Can - 68ºF

Note: The temp. difference is 3º or greater

Factor to be Applied to can Volume =

$$\frac{1 + (68^\circ - 60^\circ)\ .0000186}{1 + (65^\circ - 60^\circ)\ .0000186} = \frac{1.000148}{1.000093} = 1.000054$$

Example: Mild Steel Prover - 65ºF
Stainless Steel NBS Can – 65.5ºF

Factor to be Applied to can Volume =

$$\frac{1 + (65.5^\circ - 60^\circ)\ .0000265}{1 + (65^\circ - 60^\circ)\ \ .0000186} = \frac{1.0001458}{1.000093} = 1.0000527$$

Example: Mild Steel Prover - 50º
Stainless Steel NBS Can - 50º

Factor to be Applied to can Volume =

$$\frac{1 + (50^\circ - 60^\circ)\ .0000265}{1 + (50^\circ - 60^\circ)\ .0000186} = \frac{1 - .000265}{1 - .000186} = \frac{.99735}{.999814} = .99992$$

Example: Mild Steel Prover - 54ºF Note: The temp difference is 3º or greater
Mild Steel NBS Can - 58ºF

Factor to be Applied to can Volume =

$$\frac{1 + (58^\circ - 60^\circ)\ .0000186}{1 = 54^\circ - 60^\circ)\ \ .0000186} = \frac{1 - .0000372}{1 - .000112} = \frac{.999963}{.999888} = 1.000075$$

We would stress again that this CTS correction factor applies only when

1. The temperature difference between the NBS can and the prover is 3º or greater
2. The material of the NBS measure is different from that or the prover i.e mild steel versus stainless steel