UNDERSTANDING LIQUID METER PROVINGS AND PROVING REPORTS

Class # 4250.1

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Introduction

This paper will examine and discuss liquid meter proving reports for both mass and volume applications. Computing power has drastically affected hydrocarbon measurement in the last 15 years. The reporting and audit trail capabilities of today's measurement systems far surpass yesterday's basic proving report. This discussion will point out key elements and differences in common proving reports.

Types of Proving Reports

The two proving methodologies for liquid flow meters are volumetric and mass. Deciding which method to use depends on the quantity unit represented in the meter's frequency or K-factor. Most meter types produce a volume based pulse output (i.e. positive displacement, turbines or ultra-sonic meters). Coriolis meters are the only meter that directly measures and produces a mass pulse output, or that is proved with the mass methodology.

Volume Proves

Volumetric flow meters tend to be used with fluids with stable or known densities. Examples include crude oil, fuel oils, and high purity NGL products. These meters output a volume pulse/frequency which is compared directly to the volume of the prover. Fluid density does not play a direct role in prover volume determination as it does for mass proves.

In volume proves, the fluid density can be measured several ways. In general, for volume proves, the fluid density is used to determine volume correction factors to base conditions, instead of directly determining the prover quantity and the meter factor calculations.

Mass Proves

There are two separate mass proving methods. As previously stated, Coriolis meters can produce a mass pulse output and can be proved using direct or inferred mass methods (Reference API *MPMS* 4.8).

Direct mass proves are performed with a Coriolis master meter instead of a volume-based prover. They do not require a density determination to calculate a meter factor. The prover mass quantity is measured by the master meter prover over a period of time and is compared directly to the mass measured by the production/line meter. The mass of the prover is then divided by the meter mass to determine a meter factor.

The second method to prove the mass output of a meter is the indirect or the inferred method. Instead of meter to meter comparison, inferred or indirect mass provings utilize a conventional type volume prover to calculate prover mass quantity. The known prover volume and the flowing fluid density at prover conditions are combined to determine the prover's mass quantity. Measuring flowing density during each proving run with an online density meter provides the most accurate type of inferred mass proving and is the preferred method (Reference API *MPMS* 9.4 for online density measurement).

Prover flowing density accuracy has a direct effect on the calculation of prover mass as well as the meter factor. Flowing density stability also has a direct effect on run to run repeatability. Therefore, it is important to allow the proving system to "settle down" (stabilize before beginning proving runs). Lighter products tend to be more volatile when it comes to density fluctuation, so extra precaution should be taken to ensure a stable density.

Proving Report – Key Items

As liquid measurement software has improved, so has the reporting abilities and details. There can be an overwhelming amount of data displayed on the proving reports, so it would be prudent to point out some key items that can be of value when recalculating or analyzing results and troubleshooting proving issues.

1. Prover Information:
    - Prover Type
    - Base Prover Volume
    - Certification Date
    - Serial Number
    - Pipe ID
    - Pipe Wall Thickness
    - Area Thermal Coefficient (Ga)
    - Linear Thermal Coefficient (Gl)
2. Meter Information:
    - Meter Type
    - Meter Model
    - Serial Number
    - Pulse Output Temperature Compensated
    - Nominal K-Factor
3. Per Run Data of:
    - Meter Pressure, Temperature, Pulses
    - Prover Pressure, Temperature, and Switch Bar Temperature (for SVP provers)
    - Prover Flow Rate
    - Intermediate Meter Factor
4. Average data for volume proves of:
    - Observed or Base Fluid Density
    - Nm – Average Meter Pulses Per Run
    - IVm – Indicated Volume by the Meter for the Proving Run
    - CTSp – Correction for the Temperature of the Steel of the Prover. This correction factor corrects for the expansion of the metal pipe due to temperature change.
    - CPSp – Correction for the Effect of Pressure on the Steel of the Prover
    - CTLp/CTLm – Correction for the Effect of Temperature on the Product. This factor is applied at both the meter and prover for volume proves.
    - CPLp/CPLm – Correction for the Effect of Pressure on the Product. This factor is also applied at both the meter and the prover.
    - ISVm – Indicated Standard Volume
    - GSVp – Gross Standard Volume of the Prover
    - Meter Factor
    - Uncertainty or Repeatability Values
    - Previous Meter Factor
5. Average Proving data for mass proves of:
    - Meter Pressure, Temperature, Pulses
    - Prover Pressure, Temperature, and Switch Bar Temperature (for SVP provers)
    - Prover Flow Rate
    - IMm – Indicated Mass of the Meter; Avg N / NKF
    - Mp – Mass from the Prover; BPV * CCFp * Flowing Density
    - Meter Factor – Mp divided by ISMm
    - Prover Density at Flowing Conditions and in Meter Mass Units (i.e. lbs/BBL)
    - CTSp – Correction for the Temperature of the Steel of the Prover. This correction factor corrects for the expansion of the metal pipe due to temperature change.
    - CPSp – Correction for the Effect of Pressure on the Steel of the Prover.
    - Intermediate Meter Factor MF
    - Uncertainty or Repeatability Values
    - Previous Meter Factor

Note: CTL and CPL are typically not applied to mass proves since there are no volume corrections to base conditions is required.

Report Results

The goal of a prove is to determine a meter factor for the current operating conditions. The goal of the report is to document and provide the information necessary to recalculate the meter factor any time after the proving. The two results from a proving used to evaluate if the meter factor is acceptable are runs uncertainty value and meter factor variance.

The new meter factor is the most important item and the main answer on the report. The meter factor is almost always valid no matter what the uncertainty might be. The new meter factor should be compared to the previous to determine if that variance is within tolerances for that meter and its operating conditions.

Meter factors are calculated by dividing the prover measured quantity (mass or volume) by the meter measured quantity. Assuming that the prover is the more accurate device, a meter factor greater than 1 would mean that the flow meter is reading low. Conversely, if the meter factor is less than 1, the meter would be measuring high.

API *MPMS* 4.8 recommends that uncertainty values for the proving runs be 0.027% or less. This value is a target to predict that a meter factor is valid. Or, it is a value that indicates the confidence level of the meter factor.

Although each operator has to determine their own uncertainty tolerance, not achieving that tolerance mathematically is not an absolute pass or fail for the proving. For example, if the new meter factor is close to the previous one, but the prove has an uncertainty of 0.05%, the meter factor can still be valid because achieving 0.027% might not change the meter factor.

Historically and still a common alternative practice is to use repeatability to estimate uncertainty of the runs. Five runs that repeat at 0.05% is equivalent to 0.027% uncertainty. The number of runs does not have to be fixed at five, or any number, but can vary using either method. Figure A below provides an estimate of uncertainty for a varying number of runs and the repeatability for that number to achieve an uncertainty equivalent to 0.027%. API *MPMS* 4.8 Annex A provides details for both methods of evaluation.

Meter variance or deviation is the measure of change in meter factor from one prove to the previous prove. A typical meter or contract allowance is +/- 0.0025 shift for volume, while +/- 0.0050 for mass proves. Variance tolerances are a user defined and commonly determined from experience with or the linearity of the meter being used. If the meter factor shift is too great, then steps should usually be taken to investigate, account for, or correct for the shift. The most common reason for a shift beyond a tolerance is the two proves being compared are not at the same operating conditions.

Number of Proving Runs	Moving (Variable) Repeatability Limit
3	0.0002
4	0.0003
5	0.0005
6	0.0006
7	0.0008
8	0.0009
9	0.0010
10	0.0012
11	0.0013
12	0.0014
13	0.0015
14	0.0016
15	0.0017
16	0.0018
17	0.0019
18	0.0020
19	0.0021
20	0.0022

Figure A. Run Repeatability Criteria for 0.027% Uncertainty

Key Items as Diagnostic Tools

Numerous key items from a report can be used as diagnostic tools to troubleshoot proves that do not meet meter factor variance, repeatability or uncertainty tolerances.

- Fluid/Product Density – As product's mass is directly related to and/or calculated from the flowing density. Maintaining steady, stable product density throughout all of the proving runs is imperative to achieving repeatability. Unstable density normally means unstable temperature and pressure. Lack of repeatability for mass proves is more of a common result of unstable density than volume proves.
- Temperature and Pressure Stability, Run to Run – The greater temperatures and pressures are changing between passes or runs, the more the meter is unlikely to meet uncertainty/repeatability requirements. There is no one value or target (amount of change) for stability. Tolerances for instability varies by product type. When viewing a report that does not repeat, a quick look at the temperature and pressure for each run can highlight many issues.
- Temperature and Pressure Variations, Prove to Prove – Changes in temperature and pressure from prove to prove are one of the most common reason for meter factor shifts.
- Temperature and Pressure Differences Between Prover and Meter – The closer these values are, typically the better the prove results. Having a difference is ok but the difference should stay consistent run to run and then prove to prove.
- Flow Rate Changes, Run to Run – When the flow rate changes from run to run meters seldom repeat. Flow rate stability is one of the main key elements to achieve repeatability. A general rule of thumb is that they should not vary by more than 5%, but for most meters that is too much change.
- Flow Rate Changes, Prove to Prove – Flow rate changes prove to prove tend to increase meter factor variations.
- Number of Meter Pulses – Meter pulses are the digital output of frequency as a meter registers flow. Proving results must have meter pulses totaling greater than 10,000 per pass (20,000 on a bi-directional

prover) or use interpolated pulse collection per API *MPSM* 4.6. Few ball or sphere proves have detector accuracy to use interpolated pulses. Failure to collect enough pulses can cause meter factor shifts, repeatability issue or a bias. Reference API *MPMS* 4.2 for more details on detector accuracy.

Small volume provers (SVPs) have the switch accuracy to use interpolated pulses. They almost always have modern measurement electronics and software to collect the interpolated pulses per the standard. It is not uncommon to see proving runs from SVPs to display pulses from 100 to 8,000 per proving pass. Actual pulse count is dependent upon the meter K-Factor and prover volume, but pulse resolution is not a common problem for SVP.

Example Reports

Report formats and the information contained within the reports vary tremendously. Most reports are customized to each user's preference. Figure B-1, B-2, and C are examples of typical mass and volume reports.

Date : Time : Report Number :
Location :

Prove Data :
Diameter Inches : 17.0020 Wall Thick In : 1.1750 Elasticity: 2.800000E+07
Thermal Exp. : .0000192 Table Selected: Table E Product Name : NGL
Linear Exp.Coef: .0000096 Ambient Deg.F : 78.8
Volume bbl: .59535

Meter Data :
Serial Number: Meter ID :
Meter Size : 4" Meter Model : Coriolis Total Klb : 443314.244
K Pulses/lb : 60.000

Previous M.F. : .9960 @ KLB/hr : 2528.61 Date : 02/16/17 Time : 13:23:30

Data From Consecutive Prove Runs:

Prove Run Number	1	2	3	4	5
Forward Pulses	6373.823	6371.487	6374.489	6370.375	6377.056
Total Pulses	6373.823	6371.487	6374.489	6370.375	6377.056
Prover Density (gm/cc)	.5062	.5062	.5062	.5062	.5063
Temperature Prover Deg.F	74.5	74.5	74.5	74.5	74.6
CTSp	1.00046	1.00046	1.00046	1.00046	1.00046
Pressure Prover (PSI)	1016.5	1016.9	1017.5	1017.5	1018.7
CPSp	1.00053	1.00053	1.00053	1.00053	1.00053
Meter Density (gm/cc)	.5059	.5059	.5059	.5059	.5060
Temperature Meter Deg.F	74.5	74.5	74.5	74.5	74.5
Pressure Meter (PSI)	1029.3	1029.6	1030.0	1030.3	1030.9
Prover Volume (bbl) (Base Vol * CTSp * CPSp)	.595935	.595935	.595935	.595935	.595935
Prover Mass lb (Prover Vol*Prover Density)	105.7	105.7	105.7	105.7	105.8
Meter Mass lb (Pulses/K Factor)	106.2	106.2	106.2	106.2	106.3
Meter Factor (Prover Mass/Meter Mass)	.99525	.99570	.99529	.99596	.99499

Average Meter Factor(avg of above runs) .9956
Meter Factor Deviation Between Runs .10%

Figure B-1. Typical Mass Proving Report 1

Customer: **Oil Producer Inc**
Operator:
Location: **Pasadena, TX**
Cust Meter ID: **189052**
Meter Name: **Tank Meter #2**

Meter Data

189052 Tank Meter #2

Factor Tracked	**Meter Factor(MF)**	
Temp Compensated	**No**	
NKF	**60.0000**	**N/lb**
Manufacturer	**Micro Motion**	
Size	**4.00**	**in**
Serial No.	**189052**	
Model No.	**CMF 400**	

Prover Data

BPV	**20.0203**	**gal**
I.D.	**14.000**	**in**
W.T.	**1.988**	**in**
Manufacturer	**Calibron**	
Type	**Displacement-Piston**	
Serial No.	**ST-9409026**	
Elasticity	**2.8E7**	**1/psi**
Pipe Ga	**1.92E-5**	**1/ºF**
External Shaft Gl	**6.2E-6**	**1/ºF**
Certified		

Product Data

Name	**NGL**
Batch No.	
Flowing Density	**0.48558g/cc**
Avg Prv Tmp	**88.8**
Avg Prv Press	**905.1**
API Table	**Table E - Light Hydrocarbons (TP-27 Ex**
Base Density	
Prv Flow Density	**4.05234 lb/gal**

Tolerances

Tolerance Type: **Repeatability**
Maximum Deviation: **0.050 %**
Enabled? **Y** *Passed?* **Y** *Min # of Runs:* **5**
Criteria: **5** *out of* **5** *consecutive runs*

Avg X Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**
Prev X Factor Count Sought: **1**
Prev X Factor Count Used: **0**
Cut Off History? **N** *Cutoff Date:*

Prev Meter Factor Deviation:
Enabled? **N** *Passed?* **Y** *Prod Dep?* **N**

Proving Mode:	**Inferred Mass**
Density Mode:	**Live**
Calc. Method:	**Avg. Meter Factor**
Proving Method:	**PIU**
Passes Per Run	**3**

Proving Data

	Previous	*Current*
Task ID	**1485559452**	**1487981865**
Date	**01/27/2017**	**02/24/2017**
Time	**11:24**	**12:17**
Product	**NGL**	**NGL**
Flowrate	**1,354 lb/min**	**2,374 lb/min**
Totalizer		
Throughput		
Base Density	**0**	
Switch Bar Temp	**66.7**	**91.8**
Avg Prvr Temp	**79.6**	**88.8**
Avg Prvr Press	**910.9**	**905.1**
Repeatability	**0.040 %**	**0.020 %**
MF	**0.9981**	**0.9982**
MF Variance	**0.0000**	**0.0001**

Liquid Properties at Metering Conditions for CMF

Normal Op. Pressure	**psig**
Eq. Vapor Pressure	**psig**
CPL	

Run	TEMPERATURE Tp	Tm	PRESSURE Pp	Pm	PULSES N	Run Accepted ?		IMF	Flowrate lb/min
1	89.1	88.9	905.5	913.5	14644.623	1	Yes	0.99811	2372.361
2	88.6	88.4	904.8	912.8	14646.505	2	Yes	0.99811	2375.570
3	88.7	88.5	905.7	913.7	14644.628	3	Yes	0.99823	2373.286
4	88.6	88.4	904.5	912.5	14640.220	4	Yes	0.99812	2375.758
5	88.9	88.7	905.0	913.0	14645.546	5	Yes	0.99831	2373.462
Average	**88.8**	**88.6**	**905.1**	**913.1**	**14644.3044**			**0.99818**	**2374.088**

(1) GMp: BPV * CCFp * Flow Density

BPV	*CTSp*	*CPSp*	*F. Dens*	*GMp*
60.0609	1.00075	1.00023	4.05234	243.6260

(2) IMm: [N(avg) ÷ NKF = IMm]

N(avg)	*NKF*	*IMm*
14644.3044	60.0000	244.0720

(3) Proving Factors:

>>>>	(1)	GSMp ÷ ISMm =	0.9982	MF
	(2)	1 ÷ MF =	1.0018	MA
	(3)	NKF ÷ MF =	60.108	KF

Repeatability: **0.020 %**
Uncertainty: **0.011 %**

Trans. Serial No.	
Flow Calib Factor	4350.94.19
Density Calib Factor	5715.335
	6877.796
Frequency Set Point	
Flowrate Set Point	
Zero Verified	Zeroed
As Found	As Left

Notes

Meter Density: .4936

Figure B-2. Typical Mass Proving Report 2

Meter

Characteristics

Brand:	Coriolis	Nominal K-Factor:	200.0000 N/gal
Model:		Nominal Size:	3.00 in
Serial:		Passes Per Run:	1
Proving Mode:	Volumetric	Temp. Compensated:	No
MF Calc. Method:	Avg. Meter Factor	Interface:	PIU
Track Factor:	Meter Factor	Density Mode:	Manual

Proving Acceptance Criteria

Repeatability:	0.050 %	- Historical Deviation -	
Consistency Req.:	5 out of 5	Peform Check:	Yes
- Prior Deviation -		No. Prev. Factors:	1
Perform Check:	Yes	Max Deviation:	0.25 %
Max Deviation:	0.25 %	Historical Cutoff:	No
Prior Cutoff:	No	Product Dependent:	No
Product Dependent:	No	Use Failed Provings:	Yes
Use Failed Provings:	Yes		

Prover/Proving

Prover

Prover Class:	Displacement	Area Coeff. (Ga):	1.92E-5 1/°F
Displacer:	Piston	Elasticity:	2.8E7 psi
Brand:	Calibron	Linear Coeff. (Gl):	8.0E-7 1/°F
Serial:	ST-9409026	Upstream BPV:	0.476611 bbl
Pipe ID:	14.000 in	Cert. Date:	
Pipe Thickness:	1.988 in		

Product Data

Product:	Condensate - 2004
Product Table:	Table A - Crude Oil (2004)
Hydro. Correction:	Yes
Density:	61.1 °API
@ Temperature:	86.0 °F
@ Pressure:	0.0 psi
Equil. Vapor Pres.:	
Base Density:	58.1 °API

Proving

Run Data

Run No.	Accepted	Tp (°F)	Tm (°F)	Pp (psig)	Pm (psig)	Td (°F)	Ni	FlowRate	IMF
1	Yes	82.6	82.6	11.6	16.6	89.3	4014.563	246.575	0.99767
2	Yes	82.6	82.6	11.7	16.7	89.3	4014.432	246.962	0.99769
3	Yes	82.7	82.7	11.8	16.8	89.3	4013.975	247.478	0.99781
4	Yes	82.9	82.9	11.5	16.5	89.4	4014.644	246.136	0.99765
5	Yes	82.9	82.9	11.5	16.5	89.5	4013.441	246.114	0.99794
Average		**82.7**	**82.7**	**11.6**	**16.6**	**89.4**	**4014.2110**	**246.653**	**0.99775**

Results

- Meter -		- Prover -		- Factors -			
Nm:	4014.2110	CTSp:	1.00046	MF:	0.9978	Repeatability:	0.029 %
IVm:	20.0711	CPSp:	1.00000	CMF:	0.9979	Uncertainty:	0.015 %
CTLm:	0.98601	CTLp:	0.98601	MA:	1.0022	Passed:	Yes
CPLm:	1.00013	CPLp:	1.00009	KF:	200.44	Status:	
CCFm:	0.98614	CCFp:	0.98655	CKF:	200.42		
ISVm:	19.7929	GSVp:	19.7484	CPLo:	1.0001		

Historical Data

	Task ID	Date	Product	Flow Rate	Totalizer	Throughput	Base Dens	Repeatability	MF	MF Dev
Previous			Crude	239 gal/min			49.7 °API	0.035 %	0.9973	-0.0006
Current			Condensate - 200	247 gal/min			58.1 °API	0.029 %	0.9978	0.0005

Figure C. Typical Volume Proving Report

Conclusion

Few reports are exactly the same, but each report must contain enough information to recalculate the meter factor, identify the prover and its volume, the meter and the location of the meter.

A single proving report can contain an enormous amount of data or only the minimum. The data can be confusing unless the user has formularized themselves with the common terminology. Utilizing software with a database to maintain and/or recreate the entire meter's history can be an invaluable resource for many reasons including audit purposes. The ability to graph or chart a meter's history, with respect to a given product or based upon a flow rate range allows one to find meter factor trends and issues. Not every measurement application can provide the same level of reporting capabilities.