

# Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors

API MPMS CHAPTER 12.2

SECOND EDITION, JULY 2021

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## Foreword

API *MPMS* Chapter 12.2, 2<sup>nd</sup> Edition, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors*, supersedes the following standards, all of which are withdrawn:

- API *MPMS* Chapter 12.2.1, 2<sup>nd</sup> Edition 1995, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors—Part 1—Introduction*

- API MPMS Chapter 12.2.2, 3<sup>rd</sup> Edition 2003, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors—Part 2—Measurement Tickets*
- API MPMS Chapter 12.2.3, 1<sup>st</sup> Edition 1998, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors—Part 3—Proving Reports*

Revision of other parts of API MPMS Chapter 12.2 is ongoing. It is anticipated that:

- API MPMS Chapter 12.2.4, 1<sup>st</sup> Edition 1997, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods—Part 4—Calculation of Base Prover Volumes by Waterdraw Method*, will be superseded by API MPMS Chapter 12.4.1, *Calculation of Petroleum Quantities—Base Prover Volume Determination—Waterdraw Volumetric Method*
- API MPMS Chapter 12.2.5, 1<sup>st</sup> Edition 2001, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods—Part 5—Calculation of Base Prover Volumes by Master Meter Method*, will be superseded by API MPMS Chapter 12.4.2, *Calculation of Petroleum Quantities—Base Prover Volume Determination—Master Meter Method*

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Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, [standards@api.org](mailto:standards@api.org).

## Introduction

This standard presents the calculation procedures for dynamic measurement tickets (meter tickets), and meter proving of devices with volumetric outputs.

Earlier versions of this standard were written when mechanical desk calculators and tabulated values were widely used for calculating measurement documentation. Rules for rounding and the choice of how many figures are required for each calculation step were often made on the spot, which could result in different operators obtaining different results from the same data. Introduction of computers and solid-state scientific desk calculators improved the process, but different manufacturers' machines often produced slightly different results. To address this problem, the previous version of this standard rigorously specified the equations for computing correction factors, rules for rounding, calculation sequence, and the discrimination levels employed with the purpose of standardizing calculations to produce the same unbiased answer from given data. The implementation procedures presented in this standard are designed to use computer technology, simplify the associated arithmetic operations, and incorporate current API MPMS Chapter 11 [4] standards.

This standard does not address the differences in the raw/measured data due to differences in the precision of the instrumentation and the collection of its data. Therefore, if a continuous data system is being used on the same stream

and redundant with a discrete data system to collect and process measured quantities, it is not expected that they would necessarily produce identical results. It is expected that they both be in compliance with the guidelines in API *MPMS* Chapter 21.2 <sup>[10]</sup> and the requirements of this standard.

This standard presents two methods for data acquisition:

- 1) Discrete Method (Traditional Method)
- 2) Continuous Method (Dynamic Method)

In the Discrete Method, flow-weighted averages are used to correct the measured quantity at the end of the ticket period.

In the Continuous Method, real-time values are used to iteratively correct the measured quantity each scan cycle throughout the ticket period. Batch ticket quantities are essentially the summation of the results of each scan cycle.

In either data acquisition method, the same calculation routines are used. The only difference is intermediate rounding and the time in which the calculation is performed.

Calculations and process variable acquisitions in the Continuous Method are not continuous, but “near” continuous. As scan times in flow computers decrease, the process variable acquisition increases and will be closer to continuous.

These two methods might yield slightly different results due to the different rounding routines employed and the way the data are acquired and processed.

Reporting discrimination is only applied to the measurement ticket reported values; thus, older computer processor technology or manual calculations may not reproduce the same exact results as modern machines or manual calculations using this revised standard. Unrounded numbers in no way imply measurement accuracies to those levels. Measurement accuracies are solely dependent upon each measurement device. Identical input data should give different users equivalent results.

The intent of this document is to serve as a rigorous standard. Examples are provided to aid the user in checking computations developed using the requirements of this standard.

## 1 Scope

This document provides standardized calculation methods for the quantification of liquids, regardless of the point of origin or destination or the units of measure required by governmental customs or statute. The criteria contained in this document allow different entities using various computer languages on different computer hardware (or manual calculations) to arrive at output results within a defined tolerance within this document, using the same input data.

The document rigorously specifies the equations for computing correction factors, rules for rounding, calculation sequence, and discrimination levels to be employed in the calculations. No deviations from these specifications shall be permitted since the intent of this document is to serve as a rigorous standard. This document also covers multiple calculations as required by dynamic, online, integrated, continuous flow measurement.

## 2 Normative References

The following reference documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document applies (including any addenda or errata, or both).

API MPMS Chapter 13 (All Sections), *Statistical Aspects of Measuring and Sampling*

## 3 Terms, Definitions, Symbols, and Abbreviations

### 3.1 Terms and Definitions

For the purposes of this document the following terms and definitions apply. Terms of more general use may be found in the API MPMS Chapter 1—Online Terms and Definitions Database.

#### 3.1.1

##### **absolute density**

The mass of a substance per unit of volume at a specified temperature and pressure.

#### 3.1.2

##### **composite meter factor**

##### **CMF**

A meter factor, adjusted at the time of proving, from assumed normal operating meter pressure during the ticket period to base pressure, when it is desired to not have to calculate the correction for compressibility at the time of the measurement ticket calculation, and where it is assumed that the pressure, temperature, and density are constant during the ticket period.

#### 3.1.3

##### **flow computation device**

An arithmetic processing unit with associated memory that accepts electrically converted signals representing input variables from a liquid measurement system and performs calculations for the purpose of providing flow rate and total quantity data. It is sometimes referred to as a flow compilation device, flow computer, or tertiary device.

#### 3.1.4

##### **gross volume**

##### **GV**

The actual volume of fluids at flowing temperature and pressure as measured by a meter.

#### 3.1.5

##### **gross standard volume**

##### **GSV**

The gross volume (GV) corrected to base temperature and pressure conditions.

### **3.1.6**

#### **high vapor pressure liquid**

A liquid that at operating conditions has a vapor pressure greater than atmospheric pressure.

### **3.1.7**

#### **indicated standard volume**

##### **ISV**

The indicated volume (IV) corrected to base temperature and pressure.

### **3.1.8**

#### **indicated volume**

##### **IV**

The transferred quantity, in indicated (uncorrected) volume units, at operating conditions, that occurs between opening and closing gauges on a tank, during a meter proving with each run, or that occurs from start to stop of a receipt or delivery being measured by a flow meter.

### **3.1.9**

#### **input variable**

A data value associated with the flow or state of liquid that is input into the computer for the purpose of being part of a calculation. This input may be a measured variable from a transducer/transmitter or a manually entered fixed value. Pressure, temperature, and density are examples of input variables.

### **3.1.10**

#### **K factor**

The number of pulses generated or electronically manufactured by the meter per gross unit volume.

### **3.1.11**

#### **low vapor pressure liquid**

A liquid that at operating conditions has a vapor pressure less than or equal to atmospheric pressure.

### **3.1.12**

#### **master meter factor**

##### **MMF**

A factor used to correct the indicated volume (IV<sub>mm</sub>) of the master meter at operating conditions to the gross volume (GV<sub>mm</sub>) of the master meter at operating conditions.

### **3.1.13**

#### **measurement ticket**

The generalized term used to embrace and supersede expressions of long standing expressions such as "run ticket," "meter ticket," "receipt ticket," and "delivery ticket," that are used to document the measurement of a custody transfer of hydrocarbon liquid.

### **3.1.14**

#### **meter factor**

##### **MF**

A factor used to correct the indicated volume (IV<sub>m</sub>) of the meter at operating conditions to the gross volume (GV<sub>m</sub>) of the meter at operating conditions.

### **3.1.15**

#### **meter reading**

##### **MR**

The instantaneous display of the register on a meter head or in a flow computation device..

### **3.1.16**

#### **Net standard volume**

##### **NSV**

The gross standard volume (GSV) corrected to exclude non-merchantable components such as sediment and water (S&W).

### **3.1.17**

#### **nominal k factor**

##### **NKF**

The number of pulses generated or electronically manufactured by the meter per indicated unit volume.

### **3.1.18**

#### **pass**

A single movement of the displacer in a displacement prover that activates the start-stop detectors.

### **3.1.19**

#### **proving report**

A document showing all the meter and prover data together with all the other parameters used to calculate the reported meter factor.

### **3.1.20**

#### **proving report number**

A number that is uniquely assigned to a proving report.

### **3.1.21**

#### **quantity calculation period**

The period of time over which the calculated total quantity is to be integrated.

### **3.1.22**

#### **round trip**

The combination of a single pass of the displacer in one direction (e.g. forward) followed by a single pass of the displacer in the opposite direction (e.g. back) in a bi-directional displacement prover.

### **3.1.23**

#### **run**

One pass of the displacer between detectors on a unidirectional prover; one round trip of the displacer between detectors on a bi-directional prover; one filling or emptying of an atmospheric tank prover between the upper neck scale level reading and the lower neck scale level reading or zero reference on an open tank prover; or a single start and stop proving test run with a master meter in series with a line meter.

### **3.1.24**

#### **sampling period**

The time between the retrieval of live input variables.

### **3.1.25**

#### **weighted average**

An average in which each incremental component of the average is weighted according to its impact upon the whole.

## **3.2 Symbols and Abbreviations**

For the purposes of this document the following symbols and abbreviations apply. These symbols and abbreviations have been translated into words to aid in providing clarity and specificity of the mathematical treatments given in the text; however, the words used are not to be complete definitions. In many cases the symbols have additional letters added at the end to help clarify their meaning and application. Subscripts have been avoided. The use of capital and lower case letters is intentional in the manner portrayed.

### **Units**

SI International System of Units  
USC U.S. Customary Units

### **Pipe Dimensions**

ID Inside diameter  
OD Outside diameter  
WT Wall thickness

### **Liquid Density**

API Gravity Scale, expressed in °API, that is derived from Relative Density  
DEN Density in kilograms of mass per cubic meter (kg/m<sup>3</sup>) units  
RD Relative Density  
RHO General symbol for density, relative density, and API gravity  
RHOind RHO Indicated, at observed temperature (Tobs or Tdm) and pressure (Pobs or Pdm), of the liquid being measured by the density device, before any necessary corrections, such as HYC and DMF, have been applied  
RHOobs RHO Observed, after any necessary corrections, such as HYC and DMF, have been applied to the indicated density (RHOind)

**RHOobsWA** Flow-weighted Average, of the observed density (RHOobs) for the measurement period of the batch or sampling period at TWAdm and PWAdm

**RHObWA** Flow-weighted Average, of the base density derived from RHOobsWA.

**RHObp** Base density derived from RHOobs in Absolute Density used in meter provings.

**RHOb(avg)** Average base density for a proving obtained by averaging RHObp for each proving run or obtained from a representative sample at the start of the proving.

**RHOb** RHO at base conditions used for commodity pricing and trading using the appropriate units of measure.

**RHOtp** Calculated density at the primary quantity device, such as displacement, turbine, Coriolis, ultrasonic, at its operating temperature and pressure. This is also known in industry as RHOalt.

**RHOtpWA** Flow weighted average, of the calculated density at the primary quantity device, such as displacement, turbine, Coriolis, ultrasonic, at its operating temperature and pressure. This is also known in industry as RHOaltWA.

## Temperature

°C Units of temperature in degrees Celsius

°F Units of temperature in degrees Fahrenheit

T Temperature

Tb Temperature at base conditions

TD Temperature at the detector mounting shaft on a prover with external detectors

TD(avg) Average TD during proving or calibration

Tdm Temperature at the density meter

Tdm(avg) Average Tdm during proving or calibration

Tm Temperature at the flow meter

Tm(avg) Average Tm during proving or calibration

Tmm Temperature at the master meter

Tmm(avg) Average Tmm during proving or calibration

Tdm Temperature of the fluid observed at the hydrometer or density meter

Tp Temperature at the field prover

Tp(abg) Average Tp during proving or calibration

TWA Flow weighted average temperature during the measurement period of the batch or sampling period

TWAdm TWA for the online density meter

## Pressure

bar Units of pressure in bar

bara Bars pressure in absolute units

barg Bars pressure in gauge units

kPa Units of pressure in kilopascals

kPaa Kilopascals pressure in absolute units

kPag Kilopascals pressure in gauge units

P Pressure

Pa Pressure in absolute units

Pg Pressure in gauge units

Pb Pressure at base conditions

Pba Pb in absolute units

Pbg Pb in gauge units

PE Equilibrium vapor pressure in absolute units

PEb Equilibrium vapor pressure at base temperature in absolute units

PEG Equilibrium vapor pressure in gauge units

PEGb Equilibrium vapor pressure at base temperature in gauge units

Pdm Pressure at the density meter in gauge units

Pm Pressure at the flow meter in gauge units

Pmm Pressure at the master meter in gauge units

Pobs Pressure of the fluid observed at the hydrometer or density meter

Pp Pressure at the field prover in gauge units

Pdm(avg) Average Pdm during proving or calibration in gauge units

Pm(avg)	Average Pm during proving or calibration in gauge units
Pmm(avg)	Average Pmm during proving or calibration in gauge units
Pp(avg)	Average Pp during proving or calibration in gauge units
psi	Units of pressure in pounds per square inch
psia	Pounds per square inch in absolute units
psig	Pounds per square inch in gauge units
PWA	Flow weighted average pressure during the measurement period of the batch or sampling period
PWAdm	PWA for the online density meter in gauge units

## Correction Factors and Coefficients

CMF	Composite meter factor
CPL	Correction for the compressibility effect of pressure on a liquid
CPLnormal	CPL for calculating a composite meter factor at the normal operating pressure on a meter
CPLm	CPL for the meter during a meter proving, or measurement ticket
CPLmm	CPL for the master meter during proving
CPLp	CPL for the field prover during a meter proving
CPS	Correction for the effect of pressure on the steel
CPSp	CPS for the field prover
CSW	Correction for suspended sediment and water
CTL	Correction for the effect of temperature on a liquid
CTLm	CTL for the meter during a meter proving, calibration or measurement ticket
CTLmm	CTL for the master meter during a meter proving or calibration
CTLp	CTL for the field prover during a meter proving or calibration
CTPL	Combined temperature and pressure correction factor
CTS	Correction for the effect of temperature on the steel
CTSp	Correction for the volumetric effect of temperature on the steel of the field prover
DMF	Density meter factor, also known in industry as DCF
E	Modulus of elasticity of the steel
Ep	Modulus of elasticity of the steel of a field prover
GL	Mean coefficient of thermal linear expansion
GLp	GL for the field prover barrel
GLd	GL for the detector mounting shaft on a prover with external detectors
HYC	Hydrometer correction factor (reference API <i>MPMS</i> Chapter 9 <sup>[3]</sup> for details)
IKF	Intermediate K Factor
IMF	Intermediate meter factor
KF	K Factor
MF	Meter factor
MKF	Master meter K Factor
MMF	Master meter factor
MMFstart	MMF at the start of each master meter calibration run
MMFstop	MMF at the stop of each master meter calibration run
MMFavg	Average MMF
NKF	Nominal K Factor
NKFm	Nominal K Factor for the meter during a meter proving
NKFmm	Nominal K Factor for the master meter during a meter proving

## Volumes

BPV	Base prover volume
BPVa	Base tank prover volume adjusted for upper and lower scale readings
GSV	Gross standard volume
GSVm	GSV of the meter during a measurement ticket
GSVmm	GSV of the master meter during a meter proving
GSVp	GSV of the field prover during a meter proving
GV	Gross volume
IV	Indicated volume
IVm	IV for the meter during a meter proving or measurement ticket



IVmm	IV for the master meter during a meter proving
ISV	Indicated standard volume
ISVm	ISV for the meter during a meter proving or measurement ticket
ISVmm	ISV for the master meter during a meter proving
MMRc	Closing master meter reading
MMRo	Opening master meter reading
MPc	Closing meter pulse count
MPo	Opening meter pulse count
MRc	Closing meter reading
MRo	Opening meter reading
N	Number of whole pulses for a single proving run
Nv	Volumetric pulses used to calculate Iv
Ni	Number of interpolated pulses for a single proving run
Nib	Ni pulses corrected to base temperature or pressure conditions, or both
N(avg)	Average number of whole pulses
Ni(avg)	Average number of interpolated pulses
NSV	Net standard volume
%S&W	Volume percent of suspended sediment and water
SR	Scale reading of test measure
SRL	Lower scale reading of atmospheric tank prover
SRU	Upper scale reading of atmospheric tank prover
SWV	Sediment and water volume

## Mass

Gmass Gross mass quantity

## Special

AM	Arithmetic mean
FWA	Flow weighted average
#run	Number of unidirectional or bidirectional runs used to make one run. A single bidirectional run consists of two passes.
PV	Process variable value
j	j <sup>th</sup> sample as j varies from 1 to n
n	Number of samples
x	Represents a meter for measurement ticket, a meter during meter proving, or a master meter during meter proving. It is used to simplify writing single equations for multiple types of devices.
R%	Range percent of runs while evaluating a proving.
S&W%	Percent of S&W by volume

## 4 Field of Application

### 4.1 Applicable Fluids

This standard applies to fluids that, for all practical purposes, are considered Newtonian, single phase, and homogeneous liquids at metering conditions. Most fluids and dense phase fluids associated with the petroleum and petrochemical industries are Newtonian.

The application of this standard is limited to fluids that use appropriate density and volume correlations. If multiple parties are involved in the measurement, the method for determining the densities of the liquid should be mutually agreed upon by all concerned.

## 4.2 Reference, Standard, and Base Conditions

Historically, the measurement of petroleum liquids for both custody transfer and process control has made use of volumes and densities at specified reference conditions. Depending upon industry standards, regulations, contract language and context, these specified conditions may be termed standard conditions, base conditions, or generically, reference conditions. See Annex A for more information.

## 4.3 Defined Tolerances

For crude oil and atmospherically stable refined products, a comparison between the Continuous Method and the Discrete Method shall vary no larger than 0.01 %. For propane, the methods shall vary no larger than 0.1 %. In practice, these numbers will be an order of magnitude smaller when stable temperature and pressures are realized in a typical batch.

This difference between the Discrete Method and the Continuous Method will always exist since the CTL and CPL calculations have a nonlinear response to linear changes in temperature and pressure. See Annex B for more information outlining some scenarios showing significance.

## 5 Uncertainty

This document does not attempt to calculate uncertainty. For uncertainty calculations, reference API *MPMS* Chapter 13.3.

## 6 Precision, Rounding, and Averaging

### 6.1 Outline of Calculations

This procedure gives instructions and increments for rounding density, temperature, pressure, thermal expansion coefficient, and volume correction factor values. These rounding rules are needed to generate the final volume correction factor due to temperature and pressure and to generate the tables in printed tabular format. All input values shall be rounded when generating the tables in tabular format.

### 6.2 Register Precision and Rounding

#### 6.2.1 Precision

The physical property standard will specify the minimum precision of the device used to calculate densities and volume correction factors.

The minimum floating-point precision for calculating flow-weighted averages shall be 32bit IEEE floating point precision.

Electronic accumulator volume registers (stored result of final total volume quantity) used in continuous calculations shall be a minimum 64bit IEEE floating point precision or a scaled 32bit integer equivalent. Mechanical registers are only used in the Discrete Method and shall be used at the discrimination of the mechanical register up to the discrimination of Table 8.

Measurement tickets using calculations from an offsite calculation program, such as SCADA or DCS, may be used. When transmitting data to an offsite location, the potential arises to obtain a different result than the flow computer. To prevent this difference, the minimum precision outlined in this document shall be followed, regardless of the location of the calculation. The user should also ensure that the selected communication protocol does not alter the data from the onsite to offsite device.

### **6.2.2 Rounding**

Specific rules apply for when and where to round. When rounding is performed on input field data and output calculations, it shall be done in strict accordance with the discrimination levels in Section 7 of this document. When a number is to be rounded to a specific number of decimals, it shall always be rounded off in one step to the number of figures that are to be recorded and shall not be rounded in two or more steps of successive rounding.

The rounding procedure shall be in accordance with the following:

- a) When the figure to the right of the last place to be retained is 5 or greater, the figure in the last place to be retained should be increased by 1.
- b) If 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.

## **6.3 Averaging**

### **6.3.1 General**

Correction factors are derived using process input data such as density, temperature, and pressure. Process variables used to calculate correction factors for measurement tickets for custody transfers shall be averaged on a quantity weighted basis. Process variables and intermediate factors used to calculate a meter factor shall be averaged on an arithmetic mean basis.

### **6.3.2 Flow-weighted Averaging (FWA)**

For ticketing, all input and output calculation variables that are used to calculate gross standard volume (GSV) shall be Flow-weighted averages (FWA) which can be applied to calculation variables such as temperatures (TWA), pressures (PWA), and densities (RHO<sub>obs</sub>WA, RHO<sub>obs</sub>WA, RHO<sub>tp</sub>WA). It is essential that the calculation variables be sampled and weighted in a flow proportional manner so that high flow rates are not under sampled and low flow rates are not oversampled.

Averages on a quantity weighted basis are normally referred to as Flow-weighted averages (FWA). Gross volume shall be used to calculate flow-weighted averages.

A flow-weighted average (FWA) is not a raw instrument reading, but a mean statistical distribution of the sum of all the raw instrument readings proportional to total volume. Therefore, an FWA shall not be limited to the precision of the instrument. The reported FWA is a statistical value generated by the continuous sampling of the process variables during each calculation cycle of a sampling period (interval). The Continuous Method allows decimals to float during this process.

Process variables may be sampled based on quantity increments or time increments. Regardless of the increment performed, the variable for a given period shall be directly linked to the flow quantity for that same interval. The resulting output is the flow weighted average (FWA) of the values of that process variable.

Flow-weighted averages shall be used for measurement tickets. Time weighted averages shall not be used.

Flow-weighted averages (FWA) shall be calculated by:

$$FWA = \frac{\sum_{j=1}^n [PV_j \cdot GV_j]}{\sum_{j=1}^n [GV_j]} \quad (1)$$

where

$PV_j$  = value of the process variable sampled at the  $j^{\text{th}}$  sample as  $j$  varies from 1 to  $n$ ;

$GV_j$  = value of the incremental quantity of GV calculated at the  $j^{\text{th}}$  sample as  $j$  varies from 1 to  $n$ ;

NOTE The denominator represents the gross volume for the period.

### 6.3.3 Arithmetic Mean (AM)

Arithmetic Mean (AM) shall be calculated by:

$$AM = \frac{\sum_{j=1}^n [PV_j]}{n} \quad (2)$$

where

$PV_j$  = value of the process variable at the  $j^{\text{th}}$  sample as  $j$  varies from 1 to  $n$ .

## 7 Discrimination Levels and Discrimination Tables

In the tables that follow (Table 1 through Table 9), the number of digits shown as (X) in front of the decimal point are for illustrative purposes only and may have several digits more or less than the number of (Xs) illustrated. The number of digits shown as (x) after the decimal point are very specific, as they define the required discrimination level for each value described.

The tables in this section have letters, such as ABCD.xx, to the left of the decimal point, in this case the letters do give the actual size of the value before the decimal and are intended to be specific, not illustrative. In cases where a value is shown with the number 5 in the last decimal place, such as XX.x5, this is intended to signify that the last decimal place in the value shall be rounded to either 0 or 5, no other value being permitted. In cases where a value is shown with XX.0, round to the nearest whole number.

The discrimination levels specified in this section are in many circumstances greater than the uncertainty of the measurements. The discrimination levels outlined in this section are not implying any measurement accuracy. The discrimination levels are technically based to arrive at equivalent results mathematically from the Continuous Method and the Discrete Method calculation routines.

The Discrete Method specifies the exact discrimination in every case except for density used in the CTL calculation. The Continuous Method specifies the exact discrimination only for pipe dimensions and coefficients. Meter proving is not affected by the Discrete Method or the Continuous Method. It is a standalone concept.

The Continuous Method specifies reporting discrimination, such as display on flow computer or on printouts. It is understood that the decimals are floating behind the scenes in the calculations of the computer or printout. Initial and intermediate values in the Continuous Method are not rounded or truncated. Unrounded numbers in no way imply measurement accuracies to those levels. Measurement accuracies are solely dependent upon each measurement

device. The intent of this standard is to allow for increased accuracy and discrimination levels of inputs as they become available. Identical input data should give different users equivalent results.

NOTE In the event conventional pipe measurements are less than these discriminations, trailing zeroes may be used to accommodate the discrimination levels in Table 2.

**Table 1—Liquid Density Discrimination Levels**

	Discrete Method, Continuous Method, and Proving Reports					
	Exact/Rounded Discriminations			Unrounded/Reporting Discriminations		
	API	DEN (kg/m <sup>3</sup> )	RD and g/cc	API	DEN (kg/m <sup>3</sup> )	RD and g/cc
RHOind (For Hydrometer)	XXX.x	X XXX.xx	X.xxx xx			
RHOind (For Other Density Devices)					X XXX.xxx	X.xxx xxx
RHOb (For commodity pricing)	XXX.x	X XXX.x5	X.xxx x5			
RHOobs, RHOtp					X XXX.xxx	X.xxx xxx
RHOobsWA, RHObWA, RHOb(avg), RHOtpWA					X XXX.xxx	X.xxx xxx

**Table 2—Dimensional Discrimination Levels**

Meter Prover	Proving Reports	
	U.S. Customary (in.)	SI Units (mm)
Outside Diameter (OD)	XX.xxx x	XXX.xxx
Wall Thickness (WT)	X.xxx x	XX.xxx
Inside Diameter (ID)	XX.xxx x	XXX.xxx

**Table 3—Temperature Discrimination Levels**

	Tickets				Proving	
	Discrete Method Exact Discrimination		Continuous Method Reporting Discrimination		Discrete and Methods Exact Discrimination	
	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)
Tb	XX.0	XX.0	XX.0	XX.0	XX.0	XX.0
Tobs (For hydrometer use only)	XXX.x	XXX.xx	—	—	XXX.x	XXX.xx
Tp, TD, Tmm, Tdm, Tm	—	—	—	—	XXX.xx	XXX.xxx
TD(avg), Tdm(avg), Tm(avg), Tp(avg), Tmm(avg)	—	—	—	—	XXX.xx	XXX.xxx
TWA, TWAdm	XXX.xx	XXX.xxx	XXX.xx	XXX.xx	—	—

**Table 4—Pressure Discrimination Levels**

	Tickets		Proving
	Discrete Method	Continuous Method	Exact
	Exact	Reporting	
	(psia)	(psia)	(psia)
Pba	XX.xxx	XX.xxx	XX.xxx
	(psig)	(psig)	(psig)
Pbg	0.0	0.0	0.0
Pobs (For hydrometer use only)	X XXX.0		XXX.0
Pp, Pmm, Pdm, Pm			X XXX.x
Pdm(avg), Pm(avg), Pp(avg), Pmm(avg)			X XXX.x
PWA, PWAdm	X XXX.x	X XXX.x	
Peb, Pedm, Pem	XXX.0	XXX.0	
Pemm, Pep			XXX.0
	(kPa)	(kPa)	(kPa)
Pba	XXX.xxx	XXX.xxx	XXX.xxx
	(kPag)	(kPag)	(kPag)
Pbg	0.0	0.0	0.0
Pobs (For hydrometer use only)	X XXX.0		X XXX.0
Pp, Pmm, Pdm, Pm			XX XXX.0
Pdm(avg), Pm(avg), Pp(avg), Pmm(avg)			XX XXX.0
PWA, PWAdm	XX XXX.0	XX XXX.0	
Peb, Pedm, Pem	X XXX.0	X XXX.0	
Pemm, Pep			XX.0
	(bara)	(bara)	(bara)
Pba	X.xxx xx	X.xxx xx	X.xxx xx
	(barg)	(barg)	(barg)
Pbg	0.0	0.0	0.0
Pobs (For hydrometer use only)	XX.x		XXX.x
Pp, Pmm, Pdm, Pm			XXX.xx
Pdm(avg), Pm(avg), Pp(avg), Pmm(avg)			XXX.xx
PWA, PWAdm	XXX.xx	XXX.xx	
Peb, Pedm, Pem	XX.x	XX.x	
Pemm, Pep			XX.x

**Table 5—Discrimination Levels of Coefficients of Thermal Expansion**

	<b>Proving Reports Exact Discrimination</b>	
	<b>Linear Coefficients (GL)</b>	
<b>Type of Steel</b>	<b>U.S. Customary (per °F)</b>	<b>SI Units (per °C)</b>
Mild Carbon	<b>0.000 006 20<sup>a</sup></b>	0.000 011 16
304 Stainless	0.000 009 60	<b>0.000 017 28<sup>a</sup></b>
316 Stainless	0.000 008 90	<b>0.000 016 02<sup>a</sup></b>
174PH Stainless	<b>0.000 006 00<sup>a</sup></b>	0.000 010 80
Invar™ Rod	<b>0.000 000 80<sup>a</sup></b>	0.000 001 44
<sup>a</sup> Bold numbers are directly from the American Society of Metals (ASM) in 2020. Other numbers are derived based on customary conversions. All values apply to the temperature range 0–100 °C.		

**Table 6—Modulus of Elasticity Discrimination Levels (E)**

	<b>Proving Reports Exact Discrimination</b>		
	<b>U.S. Customary</b>	<b>SI Units</b>	<b>SI Units</b>
	<b>(psig)</b>	<b>(barg)</b>	<b>(kPag)</b>
Mild Carbon Steel	30 000 000	2 068 427.10	206 842 710
304 Stainless Steel	28 000 000	1 930 531.96	193 053 196
316 Stainless Steel	28 000 000	1 930 531.96	193 053 196
174PH Stainless	29 000 000	1 999 479.53	199 947 953
NOTE The values above were taken from the American Society of Metals (ASM) in 2020.			

**Table 7—Correction Factor Discrimination Levels**

	Tickets		Proving
	Discrete Method Exact	Continuous Method Reporting	Exact
CTSp			X.xxx xxx
CPSp			X.xxx xxx
CTL	X.xxx xxx	X.xxx xxx	X.xxx xxx
CPL	X.xxx xxx	X.xxx xxx	X.xxx xxx
CPLnormal	X.xxx xxx	X.xxx xxx	X.xxx xxx
CTPL	X.xxx xxx	X.xxx xxx	X.xxx xxx
CSW	X.xxx xx	X.xxx xx	
IMF			X.xxx xxx
CMF	X.xxx x	X.xxx x	X.xxx x
MF	X.xxx x	X.xxx x	X.xxx x
MMF	X.xxx x	X.xxx x	X.xxx x
NKF	Optional	Optional	Optional
KF	6 Significant Digits	6 Significant Digits	6 Significant Digits
IKF			7 Significant Digits
DMF	X.xxx x	X.xxx x	X.xxx x
S&W%	X.xxx	X.xxx	
NOTE For commodities that do not have a calculation routine, the discrimination shall be the discrimination defined in the CTL/CPL lookup tables with zeros added at the end to reach the precision of the discrimination tables.			



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### Table 8—Volume Discrimination Levels

U.S. Customary Units						
	Barrels			Gallons		
	Tickets		Proving	Tickets		Proving
	Discrete Method Exact	Continuous Method Reporting	Exact	Discrete Method Exact	Continuous Method Reporting	Exact
BPV, BPVa			Per Certificate			Per Certificate
SRu, SRI			Per Certificate			Per Certificate
IVm, IVmm, ISVm, ISVmm, GSVp, GSVm, GSVmm			7 Significant Digits			7 Significant Digits
IV, GSV, NSV, SWV, MRo, MRc	XXX.xx	XXX.xx		XXXX.x	XXXX.x	
SI Units						
	Cubic Meters			Liters		
	Tickets		Proving	Tickets		Proving
	Discrete Method Exact	Continuous Method Reporting	Exact	Discrete Method Exact	Continuous Method Reporting	Exact
BPV, BPVa			Per Certificate			Per Certificate
SRu, SRI			Per Certificate			Per Certificate
IVm, IVmm, ISVm, ISVmm, GSVp, GSVm, GSVmm			7 Significant Digits			7 Significant Digits
IV, GSV, NSV, SWV, MRo, MRc	XXX.xxx	XXX.xxx		XXX.0	XXX.0	

NOTE Certificate shall include discrimination levels in accordance with the applicable API *MPMS* Chapter 12 standard.

**Table 9—Mass Discrimination Levels**

<b>U.S. Customary Units</b>				
	<b>klbs</b>		<b>lbs Mass</b>	
	<b>Tickets</b>		<b>Tickets</b>	
	<b>Discrete Method Exact</b>	<b>Continuous Method Reporting</b>	<b>Discrete Method Exact</b>	<b>Continuous Method Reporting</b>
Gmass	X.xxx	X.xxx	X.0	X.0
<b>SI Units</b>				
	<b>Metric Tons (Tonnes)</b>		<b>Kilograms (kg)</b>	
	<b>Tickets</b>		<b>Tickets</b>	
	<b>Discrete Method Exact</b>	<b>Continuous Method Reporting</b>	<b>Discrete Method Exact</b>	<b>Continuous Method Reporting</b>
Gmass	X.xxx5	X.xxx5	X.5	X.5

**Table 10—Pulse Discrimination Levels**

	<b>Proving Reports Exact Discrimination</b>			
	<b>N</b>	<b>Ni</b>	<b>N(avg)</b>	<b>Ni(avg)</b>
Whole Pulse Applications	XX XXX.0		7 Significant Digits	
Pulse Interpolation Applications		XX.xxx		7 Significant Digits

## 8 Liquid Density

The density of the fluid shall be determined by appropriate technical standards. If multiple parties are involved in the measurement, the method selected for determining the fluid's density should be mutually agreed upon. Since density varies with both temperature and pressure, it shall always be expressed with the temperature and pressure of the substance associated with that density. Expressions of density such as relative density and API gravity shall also be always expressed with the associated temperature and pressure.

The Weighted Average Base Density (RHObWA) is the unrounded density that is used to calculate CTL and CPL, or CTPL. The Base Density (RHOb) is the density that is rounded from RHObWA per Section 7 for commodity pricing and trading purposes. RHOb shall not be used in any of the calculation routines.

## 9 Correction Factors

### 9.1 Overview

Calculations in this document are based on determining the merchantable net standard volume or mass from the indicated volume. Correction factors are used to adjust the metered volume to base conditions and meter factors are used to adjust a meter's indicated volume or mass to a known reference volume. Correction factors shall follow the rounding and reporting discriminations outlined in Section 7.

### 9.2 Liquid Density Correction Factors

#### 9.2.1 General

Liquid density correction factors are employed to account for changes in density because of temperature and pressure effects on the liquid. These factors convert flowing density at flowing temperature and pressure or observed density at observed temperature and pressure to base density as outlined in API *MPMS* Chapter 11<sup>[4]</sup> or other appropriate standards.

The appropriate methods for determining density are outlined in API *MPMS* Chapter 9<sup>[3]</sup>. API *MPMS* Chapter 12.2 provides specific rounding and reporting discrimination for inputs and output for density determination.

Users of glass hydrometers shall apply hydrometer correction factor (HYC) to the indicated density ( $RHO_{ind}$ ) to correct it to the observed density ( $RHO_{obs}$ ).

Users of handheld or online density meters shall apply the Density Meter Factor (DMF) to the indicated density ( $RHO_{ind}$ ) to correct it to the observed density ( $RHO_{obs}$ ).

$RHO_{obs}$  shall be used to calculate the flow weighted average observed density ( $RHO_{obsWA}$ ).

$RHO_{obsWA}$  shall be used to properly derive the flow weighted base density ( $RHO_{bWA}$ ) for CTL calculations. The commodity pricing base density ( $RHO_b$ ) is  $RHO_{bWA}$  rounded.

For some fluids (pure hydrocarbons, chemicals, solvents, etc.), a constant value may be used for base density because of stringent manufacturing specifications.

#### 9.2.2 Correction for Effect of Temperature on Liquid (CTL)

If petroleum liquid is subjected to a change in temperature, its density will decrease as the temperature rises or increase as the temperature falls. This density change is proportional to the thermal coefficient of expansion of the liquid and temperature.

The correction factor for the effect of temperature on the liquid's density is called CTL. The CTL factor is a function of the liquid's base density ( $RHO_{bWA}$ ) and temperature ( $T$ ).

The appropriate methods for determining CTL are outlined in their respective physical property standards. These methods provide the technical governance of CTL calculations. This standard provides specific rounding and reporting discrimination for inputs and output for the CTL calculation.

### **9.2.3 Correction for Effect of Pressure on Liquid (CPL)**

If petroleum liquid is subjected to a change in pressure, the liquid density will increase as the pressure rises or decrease as the pressure falls. The correction factor for the effect of pressure on liquid density is called CPL. The CPL factor is a function of the liquid's compressibility factor ( $F$ ), pressure ( $P$ ) and equilibrium vapor pressure of the liquid ( $P_e$ ) at operating conditions.

The appropriate methods for determining CPL are outlined in their respective physical property standards. These methods provide the technical governance of CPL calculations. This standard provides specific rounding and reporting discrimination for inputs and output for the CPL calculation.

The calculation of the CPL factor requires the use of the equilibrium vapor pressure ( $P_e$ ) as defined in their respective physical property standards.

The equilibrium vapor pressure ( $P_e$ ) of a fluid at any given temperature is the state in which the liquid phase and the vapor phase are in equilibrium. Liquefied petroleum gases such as propane and butane would be examples of hydrocarbon fluids with vapor pressures greater than atmospheric pressure.

Nonvolatile fluids have equilibrium vapor pressures at base temperature that are at or below atmospheric pressure. For a nonvolatile fluid, the fixed base pressure is defined by a physical properties' standard, contract, or regulation.

Volatile fluids have equilibrium vapor pressures at base temperature that are above atmospheric pressure. For a volatile fluid, the equilibrium vapor pressure at base temperature is the base pressure for that fluid.

When measuring a volatile fluid at operating pressure and temperature, the difference between the operating pressure and the equilibrium vapor pressure at that operating temperature shall be determined for calculating its  $F$  and CPL factors. The value of the equilibrium vapor pressure at operating conditions can be obtained from appropriate industry standards, using vapor pressure correlations, by the use of the correct equations of state, or by physical test at operating conditions. The method selected for determining the equilibrium vapor pressure of the fluid should be mutually agreed upon by all concerned.

### **9.2.4 Correction for Effect of Temperature and Pressure on Liquid (CTPL)**

A CTPL shall not be used if a CTL and CPL can be independently determined. A CTPL shall only be used when using an industry approved calculation such as an Equation of State (EOS), or a physical property table that does not provide an independently determined CTL and CPL.

### **9.2.5 Temperature and Pressure Compensated Meters**

In some instances, a meter's pulse output, sometimes referred to as a pulse train, may be temperature and pressure compensated to apply a CTL and CPL to the liquid in the meter. This is not to be confused with external temperature and pressure compensation applied via calculations through an external flow computation device, or temperature and pressure inputs to compensate for physical effects to the meter.

For meters that are providing a pulse output that already has CTL applied mechanically or electronically, CTL<sub>m</sub> at the flow computation device shall be set to 1.0.

For meters that are providing a pulse output that already has CPL applied mechanically or electronically, CPL<sub>m</sub> at the flow computation device shall be set to 1.0.

### 9.3 Combined Correction Factors (CCF)

Historically, the use of a CCF was implemented due to the limitations of electronic hardware, software compilers, and lack of an IEEE floating point precision standard. Since these limitations no longer exist with the use of IEEE 32bit floating registers, the use of a CCF is no longer required and has been removed from this standard.

### 9.4 Correction for Sediment and Water (CSW)

Sediment and water are considered nonmerchantable components of crude oil. The CSW is used to determine the NSV from the GSV. The CSW is determined from the %S&W as per the following expression:

$$CSW = 1 - \frac{\%S \& W}{100} \quad (3)$$

where

%S & W = volume percent sediment and water present

### 9.5 Steel Correction Factors

#### 9.5.1 Overview

Prover correction factors are employed to account for changes in the prover volume due to the effects of temperature and pressure upon the steel. These correction factors are:

- CTS—corrects for thermal expansion or contraction, or both, of the steel in the prover shell due to the average prover steel temperature.
- CPS—corrects for pressure expansion or contraction, or both, of the steel in the prover shell due to the average prover liquid pressure.

##### 9.5.1.1 Correction for the Effect of Temperature on Steel (CTS)

##### 9.5.1.2 General

Any metal container, such as a displacement prover or a tank prover, when subjected to a change in temperature, will change its dimensions accordingly. These changes, regardless of prover shape, is proportional to the coefficient(s) of thermal expansion of the material(s).

The linear coefficients of expansion for prover materials shall be the ones for the materials used in the construction of the prover. The coefficients contained in Section 7 shall be used if the coefficient(s) of expansion is unknown.

##### 9.5.1.3 CTS for Displacement Provers with Internal Detectors and Atmospheric Tank Provers

Historically, the use of a three-dimensional linear expansion term was implemented due to the limitations of electronic hardware, and software compilers. Since these limitations no longer exist the linear expansion term (GLp) is now used and is applied in the cubic equation.

The CTS correction for a free displacer type prover and an atmospheric tank prover assumes a singular construction material and may be calculated as follows:

$$CTSp = [1 + GLp * (Tp - Tb)]^3 \quad (4)$$

#### 9.5.1.4 CTS for Displacement Provers with Captive Displacers and External Detectors

A modified approach is needed for some of the displacement provers with captive displacers and external detectors. Detectors on provers with captive displacers are mounted externally, rather than on the prover barrel itself, and may have dissimilar metals and always have different temperatures. Thus, the volume changes that occur due to temperature are defined in terms of the area change in the prover barrel, and the change in distance between the detector positions. While occasionally these detector positions may be on a steel mounting that is of the same grade of steel as that of the prover barrel, it is often the case that the detector mounting rod is constructed from a grade of steel or special alloy that has a different coefficient of linear thermal expansion from that of the prover barrel. For these type of displacement provers, the correction factor for the effect of temperature (CTS) shall be modified and calculated as follows:

$$CTSp = [1 + GLp * (Tp - Tb)]^2 * [1 + GLd * (TD - Tb)] \quad (5)$$

#### 9.5.2 Correction for the Effect of Pressure on Steel (CPS)

##### 9.5.2.1 General

If a metal container such as a conventional displacement prover or a tank prover is subjected to an internal pressure, the walls of the container will stretch elastically, and the volume of the container will change accordingly.

The modulus of elasticity for prover materials shall be the ones for the materials used in the construction of the calibrated sections of the prover. The values contained in Section 7 shall be used if the modulus of elasticity is unknown.

##### 9.5.2.2 CPS for Single-walled Cylindrical Container or Prover

Although some simplifying assumptions are made in the equations below, for practical purposes the correction factor for the effect of internal pressure on the volume of a cylindrical container shall be calculated from:

$$CPSp = 1 + \frac{ID * (Pp - Pbg)}{E * WT} \quad (6)$$

$$ID = OD - (2 * WT) \quad (7)$$

##### 9.5.2.3 CPS for Double-walled Cylindrical Container or Prover

Some provers are designed with a double wall to equalize the pressure inside and outside the calibrated chamber. In this case, the inner measuring section of the prover is not subjected to a net internal pressure, and the walls of this inner chamber do not stretch elastically. Therefore, in this special case, CPS = 1.

## 9.6 K Factor (KF) and Nominal K Factor (NKF)

### 9.6.1 K Factor (KF)

A K Factor is the number of pulses generated or electronically manufactured by the meter per gross unit volume. In the special case where the pulses are directly affected by a temperature compensator, the K Factor would be the number of pulses per gross unit volume at standard temperature.

### 9.6.2 Nominal K Factor (NKF)

A Nominal K Factor is the number of pulses generated or electronically manufactured by the meter per indicated unit volume. In the special case in which the pulses are affected directly by a temperature compensator, the Nominal K Factor is the number of pulses per indicated unit volume at standard temperature. Totalizing gross and gross standard volume can be performed with a flow computation device that is configured with a Nominal K Factor which uses a fixed number of pulses per indicated volume to convert the meter output pulses to volume units.

The Nominal K Factor is configured into a flow computation device for computing volumes. The number chosen may have been the one installed by the factory, may have come from a factory test, or may have been a design value from the factory.

### 9.6.3 Scenarios Using K Factors, Nominal K Factors and Meter Factors

With the development of flow computers and their use in metering systems, two basic scenarios are used:

- 1) Scenario 1—Constant Nominal K Factor and Variable Meter Factor
- 2) Scenario 2—Constant Meter Factor of 1.0000 and Variable K Factor

### 9.6.4 Meter Factor and Composite Meter Factors

A meter factor is used to correct the indicated volume (IVm) of the meter at operating conditions to the gross volume (GVm) of the meter at operating conditions. Meter factors are calculated in Section 12 of this document.

For fluids that are governed by API MPMS Chapter 11.2.1 <sup>[6]</sup> and are operated with relatively constant pressure, a CMF may be applied. The operating pressure to calculate the CPL that normally would be present on a measurement ticket is included within the CMF.

The decision to use CMF inserts measurement uncertainty to the final quantity. For this reason, this standard will not define what is considered constant pressure. The user should perform their own sensitivity analysis to determine if the induced measurement uncertainty is acceptable. The use of CMF should be mutually agreed upon by all parties involved.

The CPL on the measurement ticket would be 1.0000 and the CMF would be calculated as follows:

$$CMF = MF * CPL_{normal} \quad (8)$$

The CMF may be used in applications where the density, temperature and pressure are approximately constant throughout the measurement period, and where the pressure is low. The CPL<sub>normal</sub> is calculated from an assumed meter pressure. The CMF is only applicable for fluids governed by API MPMS Chapter 11.2.1 <sup>[6]</sup>.

## 10 Generalized Equations for Liquid Quantity Determination

### 10.1 General

When calculating measurement quantities on a ticket, the subscript in the variables are historically omitted for discrimination between the meter and prover. For example, the CTL is written as CTL, not CTLm. Likewise, when calculating meter proving results, the discrimination between the meter and prover is preserved. For example, the CTL is written as CTLm and CTLp respectively.

For formulas that are summation, in the Continuous Method,  $n$  will vary to the number of sampling periods. In the Discrete Method, there is only 1 sampling period and  $n$  is set to 1.

### 10.2 Determination of Indicated Volume (IV)

The IV is the change in meter reading.

For indicated volume determination, the incremental IV for each sampling period shall be summed for the duration of the measurement period.

$$IV_x = \sum_{j=1}^n \left[ \frac{Nx_j}{NKF_x} \right] \quad (9)$$

where

$IV_x$  = IV, IVm, IVmm;

$Nx_j$  =  $N_v$ ,  $N$ ,  $N_m$ ,  $N_{mm}$ ,  $N_i$ ,  $N_{im}$ , at the  $j^{\text{th}}$  sample as  $j$  varies from 1 to  $n$ ;

$NKF_x$  =  $NKF$ ,  $NKF_m$ ,  $NKF_{mm}$ .

Subscript "x" can represent a meter for a measurement ticket, a meter during meter proving, or a master meter during meter proving.

When the sampling period is equal to the measurement period, alternatively, the IV may be obtained by subtracting the Opening Meter Reading (MRo) from the Closing Meter Reading (MRc):

$$IV_x = MR_c - MR_o \quad (10)$$

When an electronic flow measurement device, e.g. flow computer, SCADA system, accounting system, etc., is used to generate a measurement ticket, the IV may not always equal the result of the equation  $IV = MR_c - MR_o$  for the following reasons:

- Due to discrimination reporting requirements, remainders are carried forward to the next ticketing period and may cause the final reported IV to not always match the equation result. For example, 3689045.996851 could be reported as 3689045.99 if truncated, and the remainder, 0.006851, would be carried forward and added to the next ticketing period.
- When digital communications are used to retrieve ticketing variables from flow measurement devices the bidirectional conversion between a 64 bit (double-precision floating point) and 32 bit (single-precision floating point), does not translate into identical rounded values.
- Electronic flow measurement devices can obtain the IV incrementally during each update cycle of the measurement period instead of subtracting the opening total from the closing total.



Although the final reported IV may not always match the equation result, it should not deviate by more than one whole volume unit, as in one cubic meter or one barrel, for example.

### 10.3 Determination of Indicated Standard Volume (ISV)

The indicated standard volume (ISV) of a meter is the volume of the liquid passing through the meter with no correction for meter inaccuracies but corrected to standard conditions by the following equation:

$$ISV_x = \sum_{j=1}^n [IV_j * CTL_j * CPL_j] \quad (11)$$

where

$ISV_x$  = ISV, ISVm, ISVmm;

$IV_j$  = IV at the  $j^{th}$  sample as  $j$  varies from 1 to  $n$ ;

$CTL_j$  = CTL at the  $j^{th}$  sample as  $j$  varies from 1 to  $n$ ;

$CPL_j$  = CPL at the  $j^{th}$  sample as  $j$  varies from 1 to  $n$ .

### 10.4 Determination of Gross Volume (GV)

Gross volume of the meter at operating conditions is obtained from indicated volume by:

$$GV_x = \sum_{j=1}^n [IV_j * MF_j] \quad (12)$$

where

$GV_x$  = GV, GVm, GVmm;

$IV_j$  = IV at the  $j^{th}$  sample as  $j$  varies from 1 to  $n$ ;

$MF_j$  = MF at the  $j^{th}$  sample as  $j$  varies from 1 to  $n$ .

### 10.5 Determination of Gross Standard Volume (GSV)

The GSV of liquid flowing through a meter can be calculated for a measurement ticket by the following expression:

$$GSV_x = \sum_{j=1}^n [IV_j * MF_j * CTL_j * CPL_j] \quad (13)$$

where

$GSV_x$  = GSV, GSVm, GSVmm

$IV_j$  = IV at the  $j^{th}$  sample as  $j$  varies from 1 to  $n$ ;

$MF_j$  = MF at the  $j^{th}$  sample as  $j$  varies from 1 to  $n$ ;

$CTL_j$  = CTL at the  $j^{th}$  sample as  $j$  varies from 1 to  $n$ ;

$CPL_j$  = CPL at the jth sample as j varies from 1 to n.

Historically, while sediment and water are usually in relatively small concentrations and thus do not impact the calculation of volumes, it should be recognized that concentrations of water in oil greater than 3 % can cause significant errors in calculations from the oil and water mixture to the water free oil. For more information on this subject, see Annex C of this standard.

When a meter is proved the effects of temperature and pressure on the steel of the meter is reflected in the meter factor at the time and limited to the conditions during proving.

When calculating the gross standard volume of liquid passing through a prover during a proving run, the effects of temperature and pressure on the steel of the prover and the liquid in both the prover and the meter shall be considered.

$$GSVP = BPV * \#run * CTSp * CPSp * CTLp * CPLp \quad (14)$$

If using multi run sets, #run will equal the number of combined runs. If performing a more conventional proving, #run will equal 1, or may be eliminated. While #run is allowed, it will not be provided in the examples since this is not a common practice. For tank provers, the gross standard volume of the liquid contained in the prover between the upper (SRu) and lower (SRL) scale readings is calculated from the following:

$$GSVP = BPVa * CTSp * CPSp * CTLp * CPLp \quad (15)$$

$$BPVa = SRU - SRL \quad (16)$$

NOTE 1 For atmospheric tank provers the CPSp and CPLp are set to 1.

NOTE 2 Significance of the volume when the prover is almost empty (i.e. slightly above or below zero) precludes need for corrections. Significance of temperature in the full volume accounted for by CTS and CTL. Headstress and compressibility insignificant in atmospheric vessels of this size.

## 10.6 Determination of Net Standard Volume (NSV)

The NSV is the equivalent volume of a liquid at its base conditions that does not include non-merchantable items such as sediment and water. The formula for calculating NSV is as follows:

$$NSV = GSV * CSW \quad (17)$$

## 10.7 Determination of S&W Volume (SWV)

The sediment and water volume (SWV) is a calculated quantity based upon the percent sediment and water (%S&W) as determined by testing a representative sample of the liquid being measured. It represents the non-merchantable portion of the liquid and is calculated as follows:

$$SWV = GSV - NSV \quad (18)$$

## 10.8 Volume to Mass Calculations

### 10.8.1 Introduction and Calculations

The following equation(s) determine the mass from a measured volume.

$$G_{mass} = IV * MF * RHO_{tp} \quad (19)$$

$$G_{mass} = GV * RHO_{tp} * Conversion\ Factor(s) \quad (20)$$

Conversion factor(s) shall be applied per MPMS API Chapter 11.5 or NIST Handbook 44 to reconcile units in equations.

When mass is not directly measured, it can be inferred or calculated from other measurements. Inferred mass measurement requires online density measurement to multiply the volume of the fluid by its density in consistent units of measure, with both measured at or near the same flowing conditions of temperature and pressure as explained in API MPMS CHAPTER 9.4.

Calculated Mass Measurement utilizes a density value determined from an equation of state, a direct density measurement of a sample, a compositional analysis, or a default density value. This density value may be used to calculate the mass on a continuous, periodic, or end of batch basis.

### 10.8.2 Determination of Meter Flowing Density

The input variable for the flowing density at the meter ( $RHO_{tp}$ ) can come from several sources:

- Direct density measurement at meter conditions (inferred mass)
- Direct density measurement at other observed conditions (inferred mass)
- Density from Equations of State (calculated mass)
- Fixed base density (calculated mass)

With the exception of direct measurement at meter conditions, an applicable industry accepted method shall be used (e.g. API MPMS Chapter 11.1 For Generalized Crude Oils, Refined Products, and Lubricating Oils) to determine flowing fluid density at meter conditions ( $RHO_{tp}$ ).

#### 10.8.2.1 Direct Density Measurement at Meter Conditions

Direct density measurement at meter conditions is covered in API MPMS Chapter 9.4. The density, as determined by the density meter and corrected by the density meter factor, is used as the flowing density at the meter ( $RHO_{tp}$ ). This data can be used to calculate inferred mass measurement. The density and volume should be measured at or near the same flowing conditions.

#### 10.8.2.2 Direct density measurement at conditions other than meter conditions

When density is measured at conditions other than meter conditions, the density at observed conditions is used to calculate the density at base conditions. The density at base conditions, along with the conditions at the meter, are then used to determine the density at meter conditions to be used in calculating mass quantities from volume

quantities. For information on measuring density, see API MPMS Chapter 9.4. Calculating density at different conditions shall be done according to API MPMS Chapter 11 or another applicable industry accepted method.

$$G_{mass} = IV * MF * CTL * CPL * RHOb * Conversion\ factor(s) \quad (21)$$

Conversion factor(s) shall be applied per MPMS API Chapter 11.5 or NIST Handbook 44 to reconcile units in equations.

#### 10.8.2.3 Density from Equation of State

Equations of state, such as detailed for propylene in API MPMS Chapter 11.3.2.2, will directly calculate a density at given conditions. The density calculated by the equation at the meter conditions shall be used as flowing density at the meter ( $RHOpWA$ ) when this method of density determination is used.

#### 10.8.2.4 Fixed base density

When using a fixed base density, equation (22) shall be used to calculate mass. When calculating the correction between fixed base density and meter conditions, the appropriate API MPMS Chapter 11 or other applicable industry accepted method shall be used.

$$G_{mass} = IV * MF * CTL * CPL * RHOb(Fixed\ Base\ Density) * Conversion\ Factor(s) \quad (22)$$

Conversion factor(s) shall be applied per API MPMS Chapter 11.5 or NIST Handbook 44 to reconcile units in equation.

**NOTE** The fixed base density method is not recommended for custody transfer of unrefined products due to the variable product base density versus the specified fixed value.

### 10.9 Component Mass and Volumes from Volumetric Metering

To calculate component mass or component volume, determine mass per section 10.8, then use the methodology in API MPMS Chapter 14.4 (GPA 8173) with the appropriate fluid composition analysis. Reported quantities are rounded per the discrimination levels in Section 7.

## 10.10 Volume to Mass Calculations Sequence Flowchart

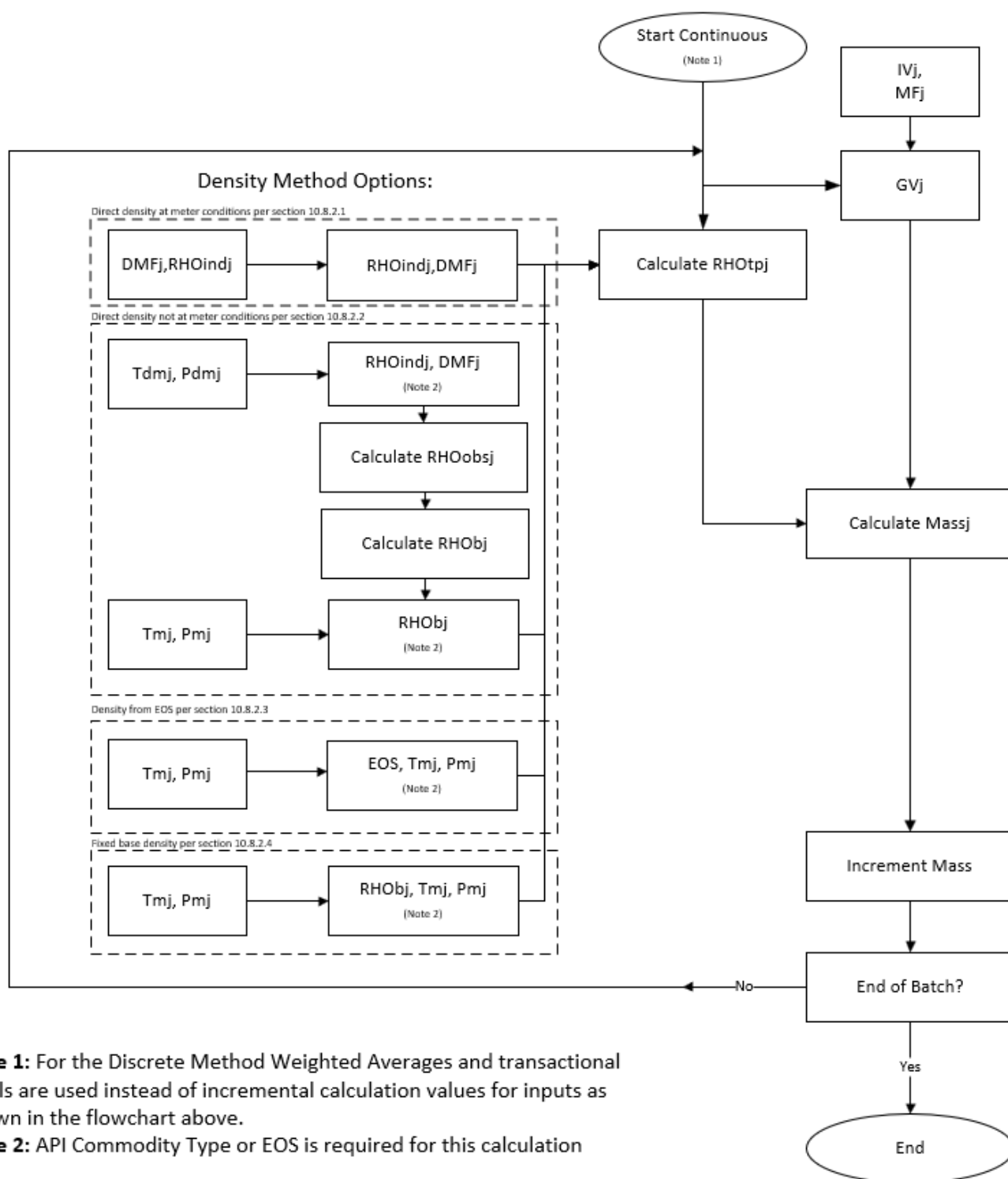


Figure 1—Volume to Mass Sequence Flowchart

## **11 Measurement Tickets**

### **11.1 General**

The purpose of standardizing the terms and arithmetical procedures employed in calculating the amount of petroleum liquid on a measurement ticket is to obtain the same unbiased answer from the same measurement data and thus avoid disagreement between the involved parties.

A measurement ticket is a documented acknowledgment of a quantity of petroleum fluids and may be deemed the legal document of transfer. The measurement ticket shall contain sufficient data required to calculate the metered quantities for comparison between the Discrete Method and Continuous Method.

Care shall be taken to ensure that all copies of a measurement ticket are legible. Corrections or erasures on a measurement ticket shall not be made unless all affected parties are notified. If corrections are made, the ticket shall be initialed, or a revision number be incremented.

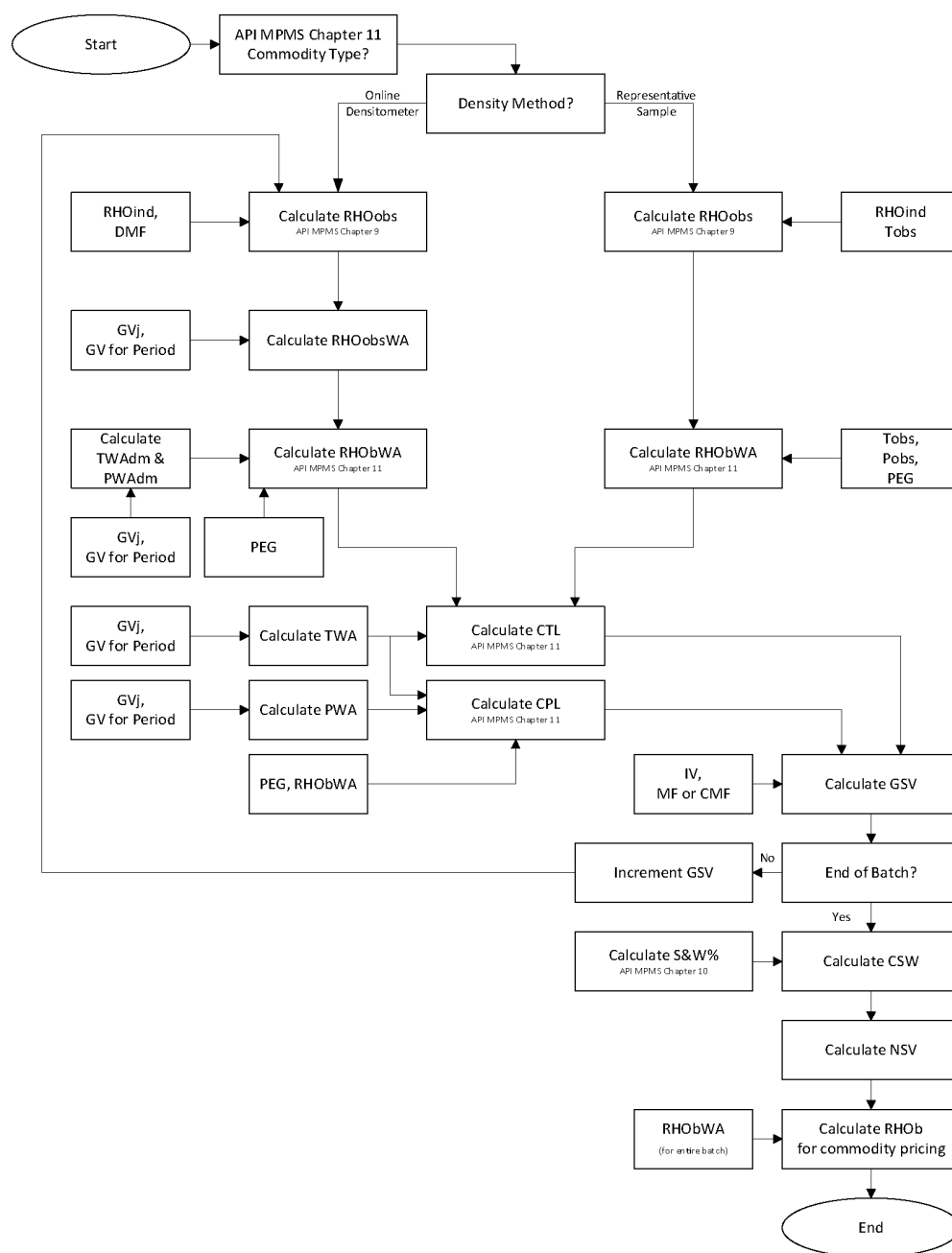
The Discrete or Continuous Method should be selected between all connected parties and potentially legal regulation authorities for calculation of measurement tickets. The method selection should not vary between measurement tickets unless all parties agree to change methodology.

Example ticket calculations are included in Annex D. The examples may be used to aid in verifying procedures for any computer routines that are developed using the requirements stated.

### **11.2 Calculation Sequence Flowchart**

The flowchart (see Figure 1) provided serves as a single calculation routine for both the Discrete Method and the Continuous Method. The quantity calculation period for the Discrete Method is usually the length of time covered by a measurement ticket. The quantity calculation period for the Continuous Method is usually much smaller than the length of time covered by a measurement ticket and can often be as frequent as the sampling period when using a flow computer. For any quantity calculation period with multiple sampling periods, input variables shall be flow-weighted averaged before use in the calculation routine.

The terms and calculations used in the chart are defined through the previous sections of this document. At each calculation step, round or report the value in accordance with Section 7.



- NOTE 1 Flow chart is for API MPMS Chapter 11 atmospherically stable fluids and fluids that require the use of equilibrium vapor pressure. Equations of state do not apply to this chart.
- NOTE 2 GVj and GV for period are considered to be the same measurement throughout the execution of this flow chart.
- NOTE 3 RHOobsWA, RHObWA shall be an Absolute Density for flow averaging purposes. RHOWA, RHOWA shall not be calculated in API gravity.
- NOTE 4 RHObis RHObWA converted to the units the commodity is traded on and rounded.
- NOTE 5 CTL = 1 for temperature compensated pulse trains.
- NOTE 6 CPL = 1 for pressure compensated pulse trains or when a CMF is used.

**Figure 2—Calculation Sequence Flowchart**

## 12 Meter Proving Reports

### 12.1 Overview

A meter proving report is a written acknowledgment of the transfer of national metrological institute certifications standards to the meter and may be deemed the legal document of record that is used in conjunction with other correction factors to correct the IV to the GSV. Proving reports shall contain the necessary field data to calculate the final calibration results. When calculating a meter factor, BPV units shall be used from the prover calibration certificate to match the NKF currently in use.

Standardizing the terms and arithmetical procedures employed in calculating the meter factor shown in a proving report allows an unbiased answer from the measurement data.

The purpose of determining a meter factor is to ensure accurate measurement for the installation effects and operating conditions on variables such as density, viscosity, flow rate, temperature, or pressure. Therefore, it shall be noted that the meter factor as calculated by this standard is the meter factor at the operating conditions at the time of proving. It is not the meter factor at base conditions, even though both the prover volume and meter volume are corrected to base temperature and pressure to establish the factor. As operational conditions change, the meter factor may shift.

Example proving report calculations are included in Annex E. The examples may be used to aid in verifying procedures for any computer routines that are developed using the requirements stated.

Corrections or erasures on a proving report shall not be made unless all affected parties are notified. If corrections are made, the ticket shall be initialed, or a revision number be incremented.

### 12.2 Meter Factor and K Factor Calculation—Intermediate Factor and Average Data Methods

#### 12.2.1 General

Two different methods are in common use for the calculation of meter factors or K Factors once a set of runs meet the repeatability requirements of the Average Data Method and the Intermediate Factor Method in 12.3. The Average Data Method uses the average of the data to determine the meter factor. The Intermediate Factor Method uses the data from each run to determine the intermediate meter factor for that run and then averages the set of intermediate meter factors to determine the meter factor. The method selected should not vary between provings unless all parties agree to change methodology.

Historically, the Average Data Method has been used since it only requires a single calculation at the end to determine the Meter Factor. The Intermediate Factor Method is the preferred method as variations in temperature and pressure are accounted for in the evaluation of the proving results.

When a set of consecutive runs is made to represent a single run in the calculations, the symbol “#run” is used to note that fact. It is understood that the uncertainties involved are not the same as if only single runs were used to represent a single run in the calculations.

#### 12.2.2 Meter Factor Calculation Intermediate Factor Method

This method calculates the meter factor (MF) using the average of the intermediate meter factors which satisfy the repeatability requirement outlined in 12.3. The intermediate meter factors are calculated from individual run process variables.



The intermediate meter factor for each proving run is calculated as follows:

$$IMF = \frac{GSV_x}{ISV_x} \quad (19)$$

where

$GSV_x$  = GSVp, GSVmm;

$ISV_x$  = ISVm, ISVmm.

The meter factor is calculated as follows:

$$MF_x = \frac{\sum_{j=1}^n [IMF_j]}{n} \quad (20)$$

where

$MF_x$  = MF, MMF;

$IMF_j$  = Value of the IMF at the  $j^{th}$  proving run as “j” varies from 1 to n;

$n$  = The number of consecutive proving runs.

### 12.2.3 K Factor Calculation—Intermediate Factor Method

This method calculates the K Factor (KF) using the average of the intermediate meter factors which satisfy the repeatability requirement outlined in 12.3. The intermediate meter factors are calculated from individual run process variables.

The intermediate K Factor for each proving run is calculated as follows:

$$IKF = \frac{N * CTL_m * CPL_m}{GSV_x} \quad (21)$$

where

$GSV_x$  = GSVp, GSVmm.

The K Factor is calculated as follows:

$$KF_x = \frac{\sum_{j=1}^n [IKF_j]}{n} \quad (22)$$

where

$KF_x$  = KF, MKF;

$IKF_j$  = Value of the IKF at the  $j^{th}$  proving run as “j” varies from 1 to n;

$n$  = The number of consecutive proving runs.

#### 12.2.4 Meter Factor Calculation Average Data Method

This method calculates the meter factor (MF) using the average of the process values from the selected runs in which the pulses satisfy the repeatability requirement outlined in 12.3.

The average process variables for use in the meter factor calculation is calculated as follows:

$$PV( avg ) = \frac{\sum_{j=1}^n [PV_j]}{n} \quad (23)$$

where

$PV_j$  = Value of the process variable at the jth proving run as j varies from 1 to n;

$PV( avg )$  = Tp(avg), Tm(avg), Pm(avg), Pp(avg), TD(avg), N(avg), Ni(avg);

$n$  = The number of consecutive proving runs.

The meter factor is calculated as follows:

$$MF_x = \frac{GSV_x}{ISV_x} \quad (24)$$

where

$MF_x$  = MF, MMF;

$GSV_x$  = GSVp, GSVmm;

$ISV_x$  = ISVm, ISVmm.

#### 12.2.5 K Factor Calculation—Average Data Method

This method calculates the K Factor (KF) using the average of the process values from the selected runs in which the pulses satisfy the repeatability requirement outlined in 12.3.

The average process variable for use in the K Factor calculation is calculated using an arithmetic mean as described in 6.3.3.

The K Factor is calculated as follows:

$$KF_x = \frac{N( avg ) * CTLm * CPLm}{GSV_x} \quad (25)$$

where

$KF_x$  = KF, MKF;

$GSV_x$  = GSVp, GSVmm.

## 12.3 Evaluating Meter Proving Run Data

### 12.3.1 General

Meter proving run data shall be evaluated in accordance with the guidelines in API *MPMS* Chapter 13. It is recommended that computers and flow computers be used for statistical evaluations of meter proving data since these calculations are generally too onerous for manual field computations. Consult API *MPMS* Chapter 4 <sup>[1]</sup> for guidance on the data set of proving results to be used for evaluation.

There are currently two practices which are acceptable for evaluating meter proving results. Calculating the standard deviation which uses the entire data set of runs and is the primary practice which will provide the most accurate representation of the repeatability of the meter.

As an alternative practice, the repeatability calculation can be achieved using a fixed range of repeatability (e.g. five runs within a range of 0.05 %) during the proving of the meter. API *MPMS* Chapter 13.2, 1<sup>st</sup> Edition, Table A.3, provides an expanded table with a moving range that lists the applicable number of runs and the required deviation limits for the associated runs. If the number of runs to be evaluated is equal to or greater than 12 runs, the true statistical standard deviation calculation should be considered as outlined in API *MPMS* Chapter 13.3, 2<sup>nd</sup> Edition, Equation 3. See also Annex E (and specifically the cautions) of API *MPMS* Chapter 13.3, 2<sup>nd</sup> Edition. This practice can be used with the Average Data Method or the Intermediate Factor Method.

Example repeatability calculations are included in Annex F. The examples may be used to aid in verifying procedures for any computer routines that are developed using the requirements stated.

### 12.3.2 Range Percent Repeatability Calculation Intermediate Factor Method

Intermediate meter factors (IMF), including intermediate master meter factors (IMMF) are calculated for each selected proving run of the prover (or filling of the tank prover). Then these intermediate meter factors shall be compared with assess their acceptable repeatability.

This model requires that the minimum and maximum IMF or IKF generated for a set of proving runs be used to calculate the repeatability.

The following equations, as appropriate, shall be used to calculate the range % for a set of data:

$$R\% = \frac{\text{Maximum IMF} - \text{Minimum IMF}}{\text{Minimum IMF}} * 100 \quad (26)$$

$$R\% = \frac{\text{Maximum IKF} - \text{Minimum IKF}}{\text{Minimum IKF}} * 100 \quad (27)$$

### 12.3.3 Range Percent Repeatability Calculation Average Data Method

This model requires that the minimum and maximum pulses generated for a set of proving runs be used to calculate the repeatability.

The following equation shall be used to calculate the range % for a set of data:

$$R\% = \frac{\text{Maximum } N(\text{avg}) - \text{Minimum } N(\text{avg})}{\text{Minimum } N(\text{avg})} * 100 \quad (28)$$

#### 12.3.4 Multiple Run Sets

Some operators may choose to perform provings with multiple run sets when standard repeatability requirements are difficult to meet. In those instances, API *MPMS* Chapter 4.8 <sup>[2]</sup> may provide guidance on the requirements for how run sets should be performed. API *MPMS* Chapter 13.3 provides the guidance on the requirements on how to calculate the uncertainty of multiple run sets. Annex G, developed from API *MPMS* Chapter 13.3, provides guidance on multiple run set uncertainty calculations, and is included in this document until it is determined whether to incorporate it into API *MPMS* Chapter 4 or Chapter 13 standards.

### 12.4 Recording of Field Data

The purpose of standardizing the terms and arithmetical procedures employed in calculating a meter proving is to obtain the same unbiased answer from the same measurement data.

Care shall be taken to ensure that all copies of a proving report are legible. Corrections or erasures on a meter proving report shall not be made unless all affected parties are notified. If corrections are made, the proving report shall be initialed, or a revision number be incremented.

At each calculation step, round or report the value in accordance with Section 8 for Discrete Method or Continuous Method.

### 12.5 Proving Reports

The following list is developed to show the required items that shall be displayed on a proving report (where applicable: not all items are used for each type of prover).

Prover Data—obtained from the calibration certificate:

- Prover or master meter manufacturer
- Prover or master meter serial number
- Type of prover: free displacer type, captive displacer type, tank prover
- Type of master meter: meter model and size
- Material of construction of prover
- Material of construction of prover rod if prover has a captive displacer and external detectors
- Base prover volume
- Inside diameter of the prover
- Wall thickness of the prover
- Modulus of elasticity of the prover
- Thermal coefficient of linear expansion of the prover
- Thermal coefficient of linear expansion for the rod if a captive displacer type prover is being used
- Master Meter Factor
- Master Meter K Factor
- Base conditions of prover calibration

Proved Meter Data:

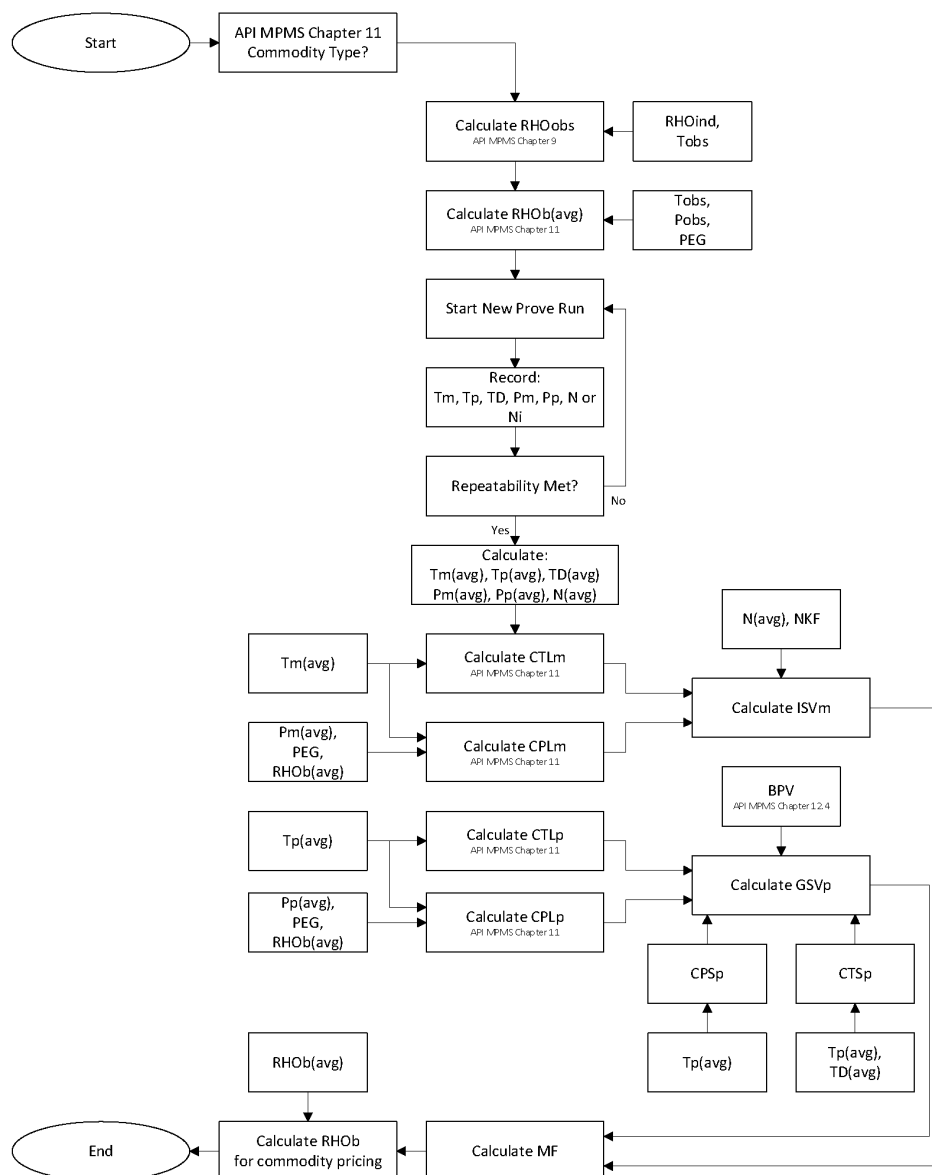
- Date of proving
- Proving report number
- Location identification
- Company assigned meter number
- Meter manufacturer, size, and model
- Meter serial number
- Flow rate at proving conditions
- Nominal K Factor
- Whether the meter pulse train is temperature compensated
- Whether the meter pulse train is pressure compensated
- The calculated factor that will be used on the ticket
- Calculation method used: Average Data Method or Intermediate Factor Method
- Evaluation model: Standard deviation uncertainty, fixed range, or moving range repeatability
  - If standard deviation, the uncertainty, and confidence interval limits shall be listed.
- Non-resettable totalizer reading

Fluid Data:

- If a batch system, batch number of the receipt or delivery
- Commodity type

## 12.6 Calculation Sequences

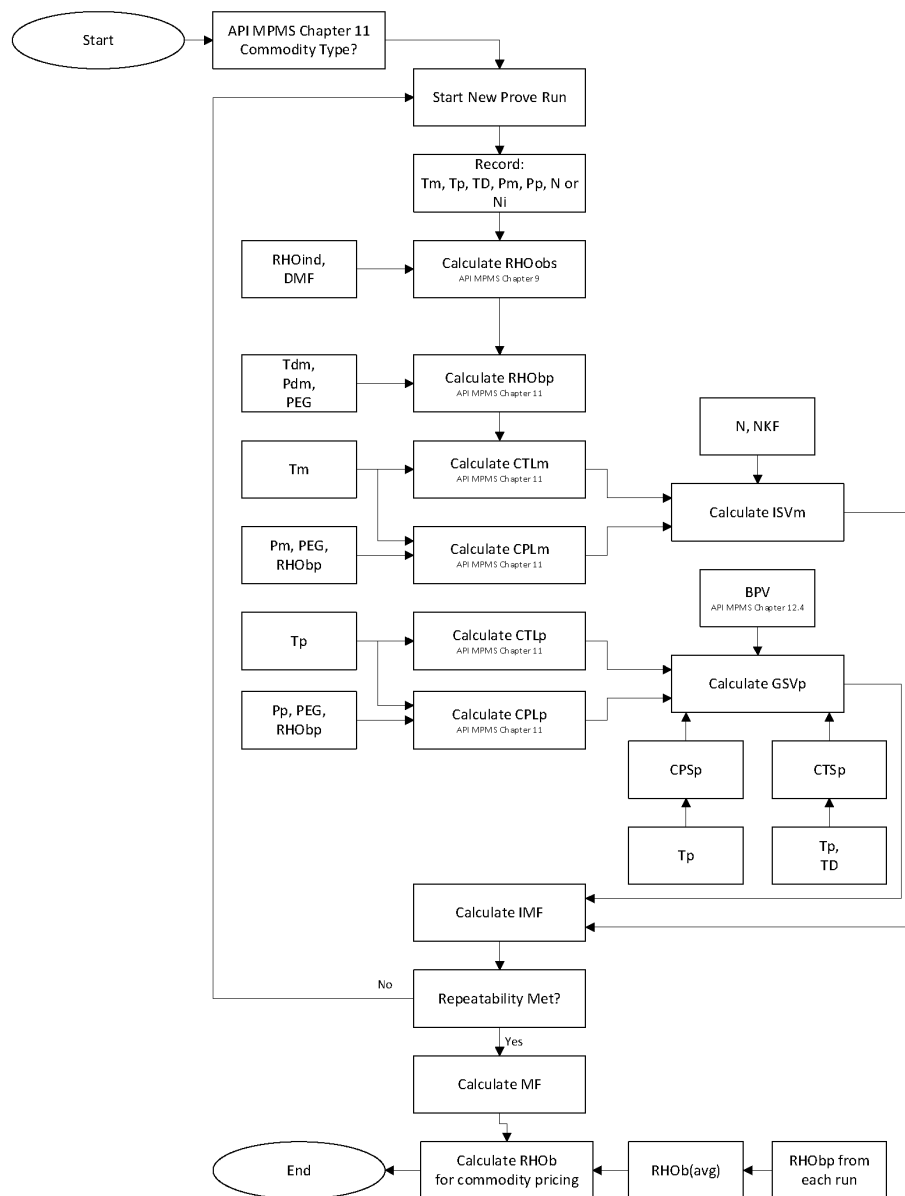
### 12.6.1 Calculation Sequence Displacement Provers with Average Data and Spot Sample



- NOTE 1 Flow chart is for API MPMS Chapter 11 atmospherically stable fluids and fluids that require the use of equilibrium vapor pressure. Equations of state do not apply to this chart.
- NOTE 2  $RHO_b(avg)$  shall be an Absolute Density for averaging purposes.  $RHO_b(avg)$  shall not be calculated in API gravity.
- NOTE 3  $RHO_b$  is  $RHO_b(avg)$  converted to the units the commodity is traded on and rounded.
- NOTE 4  $CTL_m = 1$  for temperature compensated pulse trains.
- NOTE 5  $CPL_m = 1$  for pressure compensated pulse trains.

Figure 3—Calculation Sequence Displacement Provers with Average Data and Spot Sample

## 12.6.2 Calculation Sequence Displacement Provers with Intermediate Factor and Online Densitometer



NOTE 1 Flow chart is for API MPMS Chapter 11 atmospherically stable fluids and fluids that require the use of equilibrium vapor pressure. Equations of state do not apply to this chart.

NOTE 2 RHO<sub>b</sub>(avg) shall be an Absolute Density for averaging purposes. RHO<sub>b</sub>(avg) shall not be calculated in API gravity.

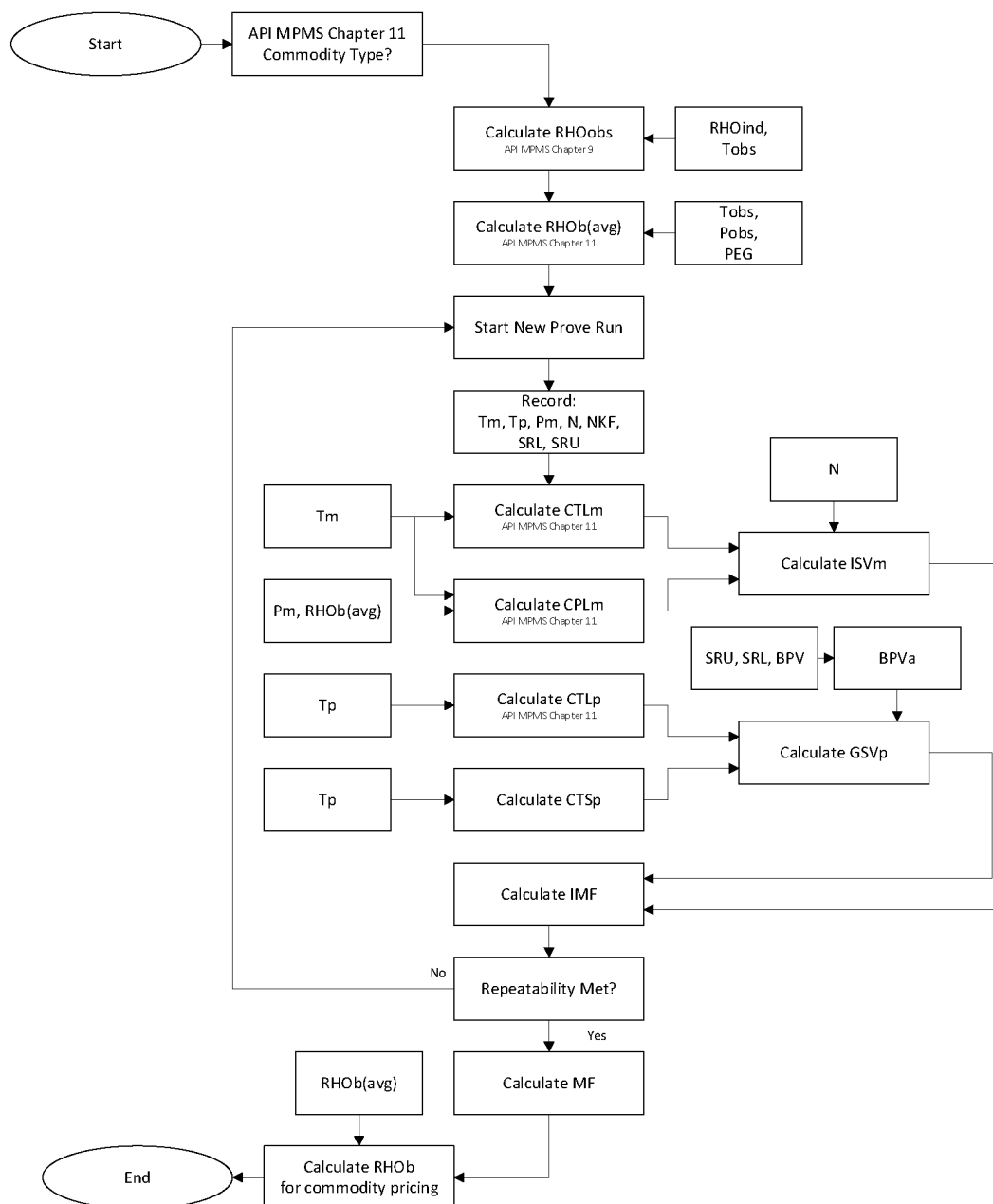
NOTE 3 RHO<sub>b</sub> is RHO<sub>b</sub>(avg) converted to the units the commodity is traded on and rounded.

NOTE 4 CTL<sub>m</sub> = 1 for temperature compensated pulse trains.

NOTE 5 CPL<sub>m</sub> = 1 for pressure compensated pulse trains.

**Figure 4—Calculation Sequence Displacement Provers with Intermediate Factor and Online Densitometer**

### 12.6.3 Calculation Sequence Atmospheric Tank Provers with Intermediate Factor and Spot Sample

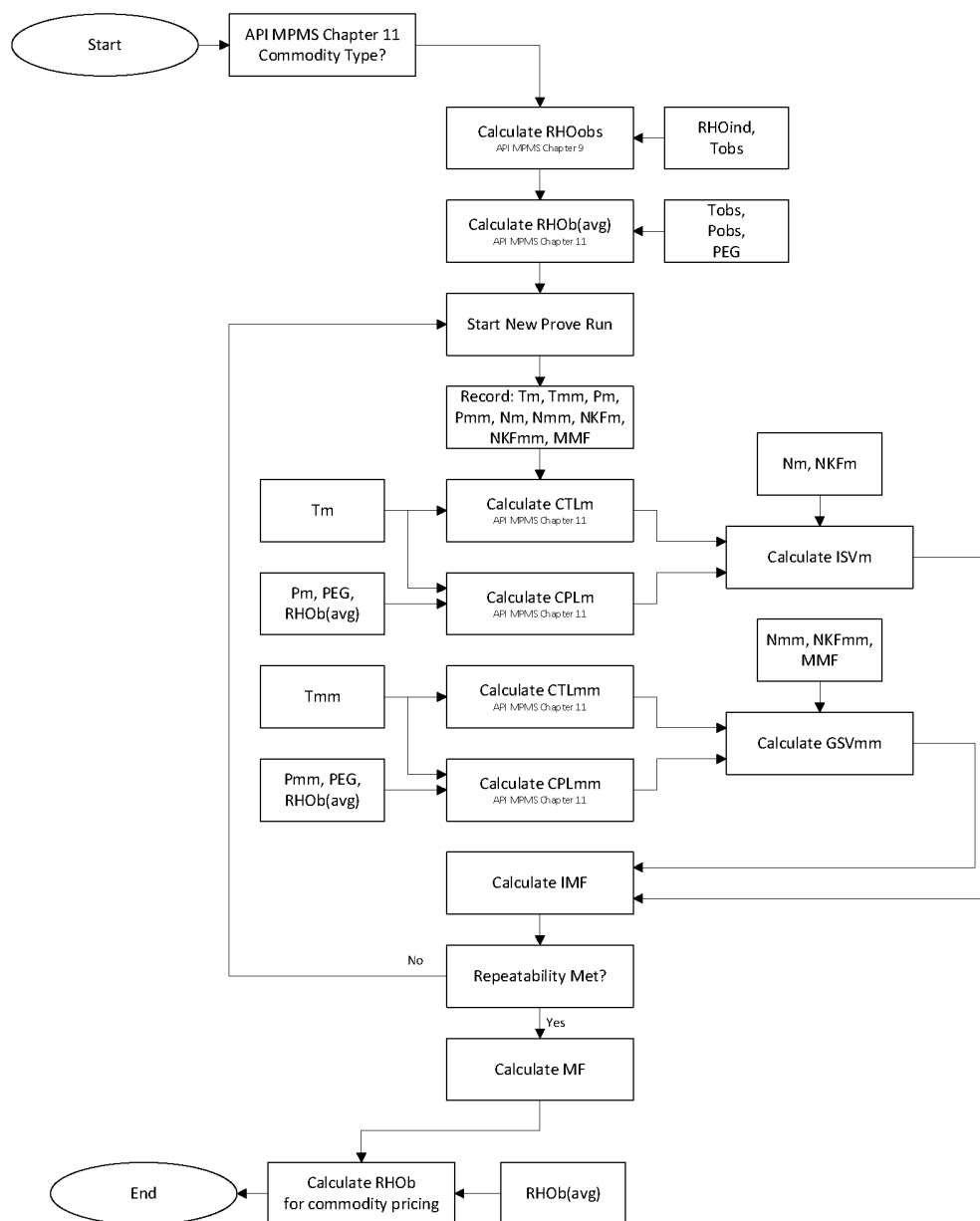


- NOTE 1 Flow chart is for API MPMS Chapter 11 atmospherically stable fluids.  
 NOTE 2 RHO<sub>b</sub>(avg) shall be an Absolute Density for averaging purposes. RHO<sub>b</sub>(avg) shall not be calculated in API gravity.  
 NOTE 3 RHO<sub>b</sub> is RHO<sub>b</sub>(avg) converted to the units the commodity is traded on and rounded.  
 NOTE 4 CTL<sub>m</sub> = 1 for temperature compensated pulse trains.  
 NOTE 5 CPL<sub>m</sub> = 1 for pressure compensated pulse trains.

**Figure 5—Calculation Sequence Atmospheric Tank Provers with Intermediate Factor and Spot Sample**



## 12.6.4 Calculation Sequence Master Meter Provers with Intermediate Factor and Spot Sample



- NOTE 1 Flow chart is for API MPMS Chapter 11 atmospherically stable fluids and fluids that require the use of equilibrium vapor pressure. Equations of state do not apply to this chart.
- NOTE 2 RHO<sub>b</sub>(avg) shall be an Absolute Density for averaging purposes. RHO<sub>b</sub>(avg) shall not be calculated in API gravity.
- NOTE 3 RHO<sub>b</sub> is RHO<sub>b</sub>(avg) converted to the units the commodity is traded on and rounded.
- NOTE 4 CTL<sub>m</sub> = 1 for temperature compensated pulse trains.
- NOTE 5 CPL<sub>m</sub> = 1 for pressure compensated pulse trains.

**Figure 6—Calculation Sequence Master Meter Provers with Intermediate Factor and Spot Sample**

## **Annex A**

### **(informative)**

## **Reference, Standard, and Base Conditions**

Historically, the measurement of all petroleum fluids, for both custody transfer and process control is stated in volumes and densities at specified reference conditions. Depending upon industry standards, regulations, contract language and context, these specified conditions may be termed standard conditions, base conditions, or generically, reference conditions. The purpose of the following examples is not to provide the user of this document the exact definitions found elsewhere, but to assist in understanding the concepts in the context of this document.

For liquid applications, standard or base conditions may vary from one country to the next due to governmental regulations or to different national standards requirements. Contract base conditions may vary as well. Therefore, for standardized volumetric flow measurement by all parties involved in the measurement at any given location, the standard or base conditions shall be identified and specified. Standard temperature and pressure conditions may or may not be equal to base conditions specific to a given contract.

The standard conditions for any one country, and the base conditions for any one contract, are to be found elsewhere. The following typical standard conditions are given only as examples <sup>1</sup>:

International System (SI) Units:

- Pressure—101.325 kPaa (14.696 psia)
- Temperature—15.00 °C (59.0 °F)

International System (SI) Units:

- Pressure—101.325 kPaa (14.696 psia)
- Temperature—20.00 °C (68.0 °F)

United States Customary (USC) Units:

- Pressure—14.696 psia (101.325 kPaa)
- Temperature—60.0 °F (15.5556 °C)

For hydrocarbon fluids having a vapor pressure that is greater than atmospheric pressure at base temperature, the base pressure shall be the equilibrium vapor pressure at base temperature.

Reference temperature and pressure conditions are:

- The specified temperature and pressure conditions of a fluid to which the volume or density of that fluid is calculated FROM an alternate temperature and pressure; or,
- The specified temperature and pressure conditions of a fluid from which the volume or density of that fluid is calculated TO an alternate temperature and pressure, or,
- The specified temperature and pressure conditions, as reported on its Report of Calibration, to which the length, area or volume of a measurement device was calculated from its calibrated length, area or volume at its calibration temperature and pressure; or,
- The specified temperature and pressure conditions from which the length, area or volume of a calibrated measurement device is calculated when used at an alternate temperature and pressure.

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<sup>1</sup>The examples are for illustration purposes only. They are not to be considered exclusive or exhaustive in nature.

Standard Temperature and Pressure Conditions are:

- The specified reference temperature and pressure conditions, used in the preparation of industry approved standard algorithms, for purposes of custody transfer of hydrocarbon fluids, at a common standard temperature and pressure; or
- The specified reference temperature and pressure conditions, defined by national or international standards, geographic regions, or state regulations and statutes, to which the density and volume of a fluid is corrected.

Base Temperature and Pressure Conditions are:

- The specified reference temperature and pressure conditions, used in the preparation of industry approved standard algorithms, for purposes of custody transfer of hydrocarbon fluids, at a common base temperature and pressure; or
- The specified reference temperature and pressure conditions, used in custody transfer for a given contract, to which the density and volume of a fluid measured at operating temperature and pressure is corrected; or,
- The specified reference temperature and pressure condition to which the length, area or volume of a measurement device is calculated, for its Report of Calibration; and from which the length, area or volume of that calibrated measurement device is calculated when used at an alternate temperature and pressure.

## **Annex B** **(informative)**

### **Defined Tolerances Scenarios**

#### **B.1 Mathematical Scenarios**

This annex demonstrates scenarios that were developed using a simulation and physical flow computers setup in a laboratory environment.

A mathematical set of scenarios were created in which extreme cases were simulated. Batches were varied by fixing 50 % of the batch at one/pressure and 50 % of the batch at a different temperature/pressure. Additionally, extreme variances of temperature/pressure were used to compound the expected error between the Discrete and Continuous Method.

- A variance of  $\pm 0.004$  % is realized for 40 °API crude oil for which:
  - The temperatures lie between 40 °F and 120 °F
  - The pressures lie between 0 and 1000 psi above atmospheric pressure
  - The range of temperatures for the total GSV is no greater than 20 °F
  - The range of pressures for the total GSV is no greater than 200 psi
- A variance of  $\pm 0.007$  % is realized for 70 °API gasoline for which:
  - The temperatures lie between 4 °F and 120 °F
  - The pressures lie between 0 and 1000 above atmospheric pressure
  - The range of temperatures for the total GSV is no greater than 20 °F
  - The range of pressures for the total GSV is no greater than 200 psi
- A variance of  $\pm 0.09$  % is realized for 0.500 RD LPG for which:
  - The temperatures lie between 40 °F and 120 °F
  - The pressures lie between 100 psi and 1000 psi above equilibrium vapor pressure
  - The range of temperatures for the total GSV is no greater than 10 °F
  - The range of pressures above equilibrium (DP) for the total GSV is no greater than 200 psi

#### **B.2 Physical Equipment Generated Scenarios**

A positive displacement (PD) meter stack driven by a variable frequency drive motor, temperature transmitter setup in 4 mA 20 mA, and a pressure transmitter setup in 4 mA 20 mA were input into the flow computer. The flow computer was setup to allow the GSV to calculate using the continuous data method. Additionally, the flow computer provided the TWA and PWA based on the Discrete Method. The decimals on the reports from the flow computer were as defined in Section 7 of this document. Table B.1 shows the comparison between the two methods.

**Table B.1—Comparison between the Discrete and Continuous Methods<Tbl\_Sideturn></Tbl\_Sideturn>**

Scenario	IV (bbls)	Discrete Method			Continuous Method	Delta (bbls)	%	Product	API	Temp. (°F)
		CTL	CPL	GSV (bbls)	GSV (bbls)					
1	257,831.32	0.989 288	1.000 333	255,154.37	255,152.72	1.65	0.000 646	Crude Oil	48	70100
2	263,134.88	0.986 619	1.000 339	259,701.88	259,703.69	1.81	0.000 696	Crude Oil	48	70100
3	235,367.64	0.989 244	1.000 333	232,913.56	232,914.59	1.03	0.000 442	Crude Oil	48	7090
4	263,811.32	0.991 899	1.000 327	261,759.75	261,760.89	1.14	0.000 435	Crude Oil	48	7080
5	240,285.75	0.986 066	1.000 456	237,045.65	237,046.63	0.98	0.000 413	Gasoline	65	7090
6	239,877.88	0.957 402	1.000 512	229,777.15	229,763.48	13.67	0.005 949	Crude Oil	60	70180
7	257,658.36	0.974 899	1.000 454	251,304.92	251,283.53	21.39	0.008 512	Crude Oil	60	40120
8	257,244.80	0.978 511	1.000 336	251,801.44	251,788.04	13.40	0.005 323	Crude Oil	44	40120

**Scenario Notes:**

- 1—Temperature variation and 30 % flow rate variation
- 2—Temperature variation and 20 % flow rate variation
- 3—Temperature variation and 20 % flow rate variation
- 4—Temperature variation and 20 % flow rate variation
- 5—Temperature variation and no flow rate variation
- 6—Temperature variation and no flow rate variation
- 7—Temperature fixed @ 40F for 62.5kbbl; Temperature fixed @ 120F for 187.5kbbl
- 8—Temperature fixed @ 40F for 62.5kbbl; Temperature fixed @ 120F for 187.5kbbl

**Conclusions:**

These scenarios show wider temperature variations than are typically seen in the real world. As shown in the table, significant temperature variations do cause some variations between the methods. If temperature swings are managed via batch cuts, this will drive the two methods towards agreement.

Scenarios 7 and 8 were developed to try and emulate using two different tanks at significant temperature differences. In this scenario, a batch should be cut for each tank to mitigate this discrepancy.

The Continuous Method will more closely represent the actual GSV for the measurement period due to the nature of the CTL curve as it relates to temperature. Since both methods of continuous and discrete are allowed in industry, operators should monitor temperature swings within the measurement ticket and split the measurement ticket accordingly when using the Discrete Method.

## Annex C (informative)

### Water in Oil Density Impacts

While sediment and water are usually in relatively small amounts and thus do not impact the calculation of GSV and NSV, it should be recognized that large amounts of water cause a significant shift in density from the oil water mixture to the water free oil. Produced water often has more effect than distilled water. The following will illustrate.

The density of the mixture is the combination of the oil density and water density. It is important to note that when measuring the density of the mixture, a hydrometer or densitometer is also measuring the combined density. The following example<sup>2</sup> illustrates how to calculate the density of the oil if there was no water present.

In this example (see Table C.1), a density of 47.4 was determined via a glass hydrometer. The sample was then determined to have a 3 % reading via the centrifuge method.

Centrifuge Tubes:

- Sample mixture—100 mL
- Water Vol—3 mL
- Water %—3 %

**Table C.1—Water in Oil Density Impacts**

	APIb	RDb	g/cc
Mixture 100 mL	47.4	0.790945	0.790167
Water 3 mL	9.00	1.007117	1.006126
Oil 97 mL	48.93	0.784259	0.783488
NOTE Production water is more dense than distilled water.			

$$RD_{mixture} = \frac{141.5}{131.5 + API_{mixture}} \quad (C.1)$$

$$Oil\% = 100\% - Water\% \quad (C.2)$$

$$RD_{oil} = \frac{RD_{mixture} - Water\% * RD_{water}}{Oil\%} \quad (C.3)$$

$$API_{oil} = \frac{141.5}{RD_{oil}} - 131.5 \quad (C.4)$$

$$g / cc = RD * 0.999016 \quad (C.5)$$

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<sup>2</sup>This example is for illustration purposes only. It is not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

## **Annex D** **(informative)**

### **Measurement Ticket Examples**

The following examples (Figure D.1 through Figure D.6) have been provided to give guidance on the calculations that should be displayed on a measurement ticket:

Figure D.1—Crude Oil, Hydrometer, Meter Factor

Figure D.2—Gasoline, Densitometer, Meter Factor

Figure D.3—Jet, Hydrometer, Composite Meter Factor

Figure D.4—Diesel, Hydrometer, Temperature Compensated, Composite Meter Factor

Figure D.5— Direct density measurement at conditions other than meter conditions

Figure D.6—Equation Of State

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Midstream Metering Location  
Meter Receipt

Ticket Nbr: 123456  
Facility: Midstream Measurement  
Facility Owner: Midstream Partners  
Product: Crude Oil  
Batch Number: 54321

Meter Equipment Data:

Meter Number:	F200	Description:	South Midstream Location
Serial Number:	132435	Proving Number:	43103
Meter Type:	PD	Calibration Date:	1/1/2019
Temperature Compensated:	N	Meter Factor:	0.9989
Pressure Compensated:	N	Density Type:	Glass Hydrometer
Factor Type:	MF	Density Factor:	N/A

Meter Reading Data:

Closing:	47,677.782 M3	FWA Temperature (TWA):	22.125 °C
Opening:	31,785.188 M3	FWA Pressure (PWA):	1034.21 kPa
Indicated:	15,892.594 M3		

Fluid Properties Data:

Sample Gravity (API <sub>obs</sub> )	844.15 kg/m3	Equilibrium Vapor Pressure (PE)	N/A kPa
Obs. Pressure (P <sub>obs</sub> )	N/A kPa	FWA Density (RHO <sub>obs</sub> WA)	N/A
Obs. Temp (T <sub>obs</sub> )	22.05 °C	FWA Density Temperature (TWA <sub>adm</sub> )	N/A
S&W:	0.2 %	FWA Density Pressure (PWA <sub>adm</sub> )	N/A

Calculations:

RHO <sub>b</sub> WA:	849.139 kg/m3								
IV	*	MF	*	CTL	*	CPL	=	GSV	
15,892.594	*	0.9989	*	0.994062	*	1.000783	=	15,793.202	
GSV	*	CSW	=	NSV					
15,793.20	*	0.99800	=	15,761.616					
GSV	-	NSV	=	SWV					
15,793.20	-	15,761.62	=	31.586					

Financial Ticketing Quantities:

GSV: 15,793.202 m3  
SWV: 31.586 m3  
NSV: 15,761.616 m3  
RHO<sub>b</sub>: 849.10 kg/m3

Remarks:

Opening

Gauger:  
Internal Witness:

Date:  
External Witness:

Time:

Closing

Gauger:  
Internal Witness:

Date:  
External Witness:

Time:

Issued:

Figure D.1—Crude Oil, Hydrometer, Meter Factor



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Midstream Metering Location  
Meter Receipt

Ticket Nbr: 123456  
Facility: Midstream Measurement  
Facility Owner: Midstream Partners  
Product: Gasoline  
Batch Number: 54321

Meter Equipment Data:

Meter Number:	F200	Description:	South Midstream Location
Serial Number:	132435	Proving Number:	43103
Meter Type:	Helical Turbine	Calibration Date:	1/1/2019
Temperature Compensated:	N	Meter Factor:	1.0002
Pressure Compensated:	N	Density Type:	Online Densitometer
Factor Type:	MF	Density Meter Factor:	0.9997

Meter Reading Data:

Closing:	300,000.00	BBLS	FWA Temperature (TWA):	85.12 °F
Opening:	200,000.00	BBLS	FWA Pressure (PWA):	201.2 PSIG
Indicated:	100,000.00	BBLS		

Fluid Properties Data:

Sample Gravity (APIind)	N/A °API	FWA Density (RHOobsWA)	723.017	kg/m3
HYC Corrected Density (RHObs)	N/A kg/m3	FWA Density Temperature (TWAdm)	85.28	°F
Obs. Pressure (Pobs)	N/A PSIG	FWA Density Pressure (PWAdm)	195.30	PSIG
Obs. Temp (Tobs)	N/A °F	Equilibrium Vapor Pressure (PE)	N/A	PSIA
S&W:	0.000 %			

Calculations:

RHO <sub>b</sub> WA:	734.649	kg/m3							
IV	*	MF	*	CTL	*	CPL	=	GSV	
100,000	*	1.0002	*	0.982615	*	1.001743	=	98,452.46	
GSV	*	CSW	=	NSV					
98,452.46	*	1.00000	=	98,452.46					
GSV	-	NSV	=	SWV					
98,452.46	-	98,452.46	=	0					

Financial Ticketing Quantities:

GSV: 98,452.46 bbls  
SWV: - bbls  
NSV: 98,452.46 bbls  
APIb: 60.9 °API, 60 °F, 0 PSIG

Remarks:

Opening

Gauger:  
Internal Witness:

Date:  
External Witness:

Time:

Closing

Gauger:  
Internal Witness:

Date:  
External Witness:

Time:

Issued:

Figure D.2—Gasoline, Densitometer, Meter Factor

Midstream Metering Location  
Meter Receipt

Ticket Nbr: 123456  
  
Facility: Midstream Measurement  
Facility Owner: Midstream Partners  
Product: Jet  
Batch Number: 54321

Meter Equipment Data:

Meter Number:	F200	Description:	South Midstream Location
Serial Number:	132435	Proving Number:	43103
Meter Type:	PD	Calibration Date:	1/1/2019
Temperature Compensated:	N	Composite Meter Factor:	1.0012
Pressure Compensated:	N	Density Type:	Glass Hydrometer
Factor Type:	CMF	Density Meter Factor:	N/A

Meter Reading Data:

Closing:	300,000.00	BBLS	FWA Temperature (TWA):	77.52 °F
Opening:	200,000.00	BBLS	FWA Pressure (PWA):	N/A PSIG
Indicated:	100,000.00	BBLS		

Fluid Properties Data:

Sample Gravity (APIind)	47.2 °API	FWA Density (RHOobsWA)	N/A
HYC Corrected Density (RHOobs)	790.887 kg/m3	FWA Density Temperature (TWA <sub>Adm</sub> )	N/A
Obs. Pressure (Pobs)	0.0 PSIG	FWA Density Pressure (PWA <sub>Adm</sub> )	N/A
Obs. Temp (Tobs)	76.0 °F	Equilibrium Vapor Pressure (PE)	N/A PSIA
S&W:	0.000 %		

Calculations:

RHO <sub>b</sub> WA:	797.532	kg/m3							
IV	*	CMF	*	CTL	*	CPL	=	GSV	
100,000	*	1.0012	*	0.990875	*	1.000000	=	99,206.41	
GSV	*	CSW	=	NSV					
99,206.41	*	1.00000	=	99,206.41					
GSV	-	NSV	=	SWV					
99,206.41	-	99,206.41	=	0.00					

Financial Ticketing Quantities:

GSV: 99,206.41 bbls  
SWV: - bbls  
NSV: 99,206.41 bbls  
APIb: 45.7 °API, 60 °F, 0 PSIG

Remarks:

Opening

Gauger:  
Internal Witness:

Date:  
External Witness:

Time:

Closing

Gauger:  
Internal Witness:

Date:  
External Witness:

Time:

Issued:

Figure D.3—Jet, Hydrometer, Composite Meter Factor

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Midstream Metering Location  
Meter Receipt

Ticket Nbr: 123456  
Facility: Midstream Measurement  
Facility Owner: Midstream Partners  
Product: Diesel  
Batch Number: 54321

Meter Equipment Data:

Meter Number:	F200	Description:	South Midstream Location
Serial Number:	132435	Proving Number:	43103
Meter Type:	Turbine	Calibration Date:	1/1/2019
Temperature Compensated:	Y	Composite Meter Factor:	1.0009
Pressure Compensated:	N	Density Type:	Glass Hydrometer
Factor Type:	CMF	Density Factor:	N/A

Meter Reading Data:

Closing:	295,970.00 BBLs	FWA Temperature (TWA):	N/A °F
Opening:	200,000.00 BBLs	FWA Pressure (PWA):	N/A PSIG
Indicated:	95,970.00 BBLs		

Fluid Properties Data:

Sample Gravity (APIind)	37.5 °API	FWA Density (RHOobsWA)	N/A
HYC Corrected Density (RHOobs)	836.162 kg/m3	FWA Density Temperature (TWA <sub>adm</sub> )	N/A
Obs. Pressure (Pobs)	0.0 PSIG	FWA Density Pressure (PW <sub>adm</sub> )	N/A
Obs. Temp (Tobs)	87.0 °F	Equilibrium Vapor Pressure (PE)	N/A PSIA
S&W:	0.000 %		

Calculations:

RHO <sub>bWA</sub> :	846.808 kg/m3								
IV	*	CMF	*	CTL	*	CPL	=	GSV	
95,970	*	1.0009	*	1.000000	*	1.000000	=	96,056.37	
GSV	*	CSW	=	NSV					
96,056.37	*	1.00000	=	96,056.37					
GSV	-	NSV	=	SWV					
96,056.37	-	96,056.37	=	0.00					

Financial Ticketing Quantities:

GSV: 96,056.37 bbls  
SWV: - bbls  
NSV: 96,056.37 bbls  
APIb: 35.4 °API, 60 °F, 0 PSIG

Remarks:

Opening  
Gauger: \_\_\_\_\_ Date: \_\_\_\_\_ Time: \_\_\_\_\_  
Internal Witness: \_\_\_\_\_ External Witness: \_\_\_\_\_  
Closing  
Gauger: \_\_\_\_\_ Date: \_\_\_\_\_ Time: \_\_\_\_\_  
Internal Witness: \_\_\_\_\_ External Witness: \_\_\_\_\_

Issued:

Figure D.4—Diesel, Hydrometer, Temperature Compensated, Composite Meter Factor

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Midstream Metering Location  
Meter Receipt

Ticket Nbr:123456

Facility:Midstream Measurement  
Facility Owner:Midstream Partners  
Product:Gasoline  
Batch Number:54321

Meter Equipment Data

Meter Number:	F200	Description:	South Midstream Location
Serial Number:	132435	Proving Number:	24680
Meter Type:	Helical Turbine	Calibration Date:	1/1/2024
Temperature Compensated:	N	Meter Factor:	1.0002
Pressure Compensated:	N	Density Type:	Online Densitometer
Factor Type:	MF	Density Meter Factor:	0.9997

Meter Data

Closing:	50,268,170.00	BBLs	FwA Temperature (TwA):	85.12	F
Opening:	50,261,725.00	BBLs	FwA Pressure (PwA):	201.2	PSIG
Indicated:	6,445.00	BBLs			

Fluid Properties Data

Sample Gravity (APIInd)	N/A	API	FwA Indicated Density (RHOInd)	0.722799	g/cc
HYC Corrected Relative Density (RHObs)	N/A		FwA Observed Density (RHOobs)	0.722582	g/cc
Obs. Pressure (Pobs)	N/A	PSIG	FwA Density Temperature (TwAdm)	85.28	F
Obs. Temp (Tobs)	N/A	F	FwA Density Pressure (PwAdm)	195.3	PSIG
S&W:	N/A	%	Equilibrium Vapor Pressure (PE)	N/A	PSIA

Volume & Mass Calculations

Density

RHO <sub>b</sub> wA:	0.734216	g/cc	RHO <sub>t</sub> pW <sub>A</sub> :	0.722700	g/cc
----------------------	----------	------	------------------------------------	----------	------

Volume

IV (BBLs)	*	MF	=	GV (BBLs)
6,445.00	*	1.0002	=	6446.29

Mass

GV (BBLs)	*	gals/BBL	*	cwt/gal	*	RHO <sub>t</sub> p (g/cc)	/	g/lb.	/	lbs./kibs.	=	Gross Mass (Klbs)
6,446.29	*	42	*	3785.411784	*	0.722700	/	453.59237	/	1000	=	1632.919

Conversion Factors

453.59237 g/lb.  
3785.411784 cwt/gal  
42 gals/BBL

Final Ticket Quantities

GV	6446.29	BBLs
Gross Mass	1632.919	Klbs

Notes:

1. Density calculations per API MPMS 11.1 (2004).  
2. Conversion Factors per NIST Handbook 44 - 2024, Appendix C: General Tables of Units of Measurement.

Remarks:

Opening

Gauger:  
Internal Witness:

Date:  
External Witness:

Time:

Closing

Gauger:  
Internal Witness:

Date:  
External Witness:

Time:

Issued:

Figure D.5— Direct density measurement at conditions other than meter conditions

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Midstream Metering Location  
Meter Receipt

Ticket Nbr: 123456  
Facility: Midstream Measurement  
Facility Owner: Midstream Partners  
Product: Propylene  
Batch Number: 54321

Meter Equipment Data:

Meter Number:	F200	Description:	South Midstream Location
Serial Number:	132435	Proving Number:	43103
Meter Type:	Turbine	Calibration Date:	1/1/2019
Temperature Compensated:	N	Meter Factor:	0.9982
Pressure Compensated:	N	Density Type:	EOS API MPMS CHAPTER 11.3.3.2
Factor Type:	MF	Density Meter Factor:	N/A

Meter Reading Data:

Closing:	1,459,443.00	BBLS	FWA Temperature (TWA):	81.80 °F
Opening:	1,446,174.00	BBLS	FWA Pressure (PWA):	903.3 PSIG
Indicated:	13,269.00	BBLS		

Fluid Properties Data:

Sample Gravity (APIind)	N/A	°API	FWA Density (RHOobsWA)	N/A
HYC Corrected Density (RHOobs)	N/A	kg/m3	FWA Density Temperature (TWA <sub>adm</sub> )	N/A
Obs. Pressure (Pobs)	N/A	PSIG	FWA Density Pressure (PWA <sub>adm</sub> )	N/A
Obs. Temp (Tobs)	N/A	°F	Equilibrium Vapor Pressure (PE)	N/A PSIA
S&W:	N/A	%		

Calculations:

IV	•	MF	=	GV	•unrounded
13,269	•	0.9982	=	13245.1158	
GV	•	RHO <sub>tpWA</sub>	=	Gross MASS	
13,245	•	181.4223	=	2402.959	

Financial Ticketing Quantities:

Gross Mass: 2,402.959 KLBS  
RHO<sub>tpWA</sub>: 181.4 lb/bbl @81.8°F, 903.3PSIG

Remarks:

Opening

Gauger: Date: Time:  
Internal Witness: External Witness:

Closing

Gauger: Date: Time:  
Internal Witness: External Witness:

Issued:



Figure D.6— Equation Of State

## **Annex E** **(informative)**

### **Proving Report Examples**

The following examples (Figure E.1 through Figure E.4) have been provided to give guidance on the calculations that should be displayed on a proving report:

**Figure E.1**—Displacement Prover, Average Data, Fixed Range, Spot Sample

**Figure E.2**—Captive Displacer Prover, Intermediate Factor, Fixed Range, Online Density

**Figure E.3**—Tank Prover, Intermediate Factor, Fixed Range, Spot Sample

**Figure E.4**—Master Meter, Intermediate Factor, Moving Range, Spot Sample

These examples are not intended to be all inclusive as multiple other combinations of products, equipment configuration, and units exist. The following examples are for illustration purposes only. They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

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# OPERATOR

# LOCATION

API MPMS Chapter 12.2	Midstream Metering Location
-----------------------	-----------------------------

# METER DATA

Meter ID Number:	200	MF, CMF, or KF	MF	MFG & Model	Co ABC, PD
Totalizer Reading:	1,642,509.00 BBLS	Meter Type	PD	Serial No.	PD-6822
Temp. Compensated	NO	Meter Size	10 in	NKF	1,000
Press. Compensated	NO	Density Type	Hydrometer		

# PREVIOUS PROVING REPORT

# CURRENT PROVING REPORT

Date	October 18, 2018	Date	November 18, 2018
Report Number	10	Report Number	11
Totalizer Reading	1,543,999.47 BBLS	Totalizer Reading	1,642,509.06 BBLS
Flow Rate	4,000 BPH	Flow Rate	4,000 BPH
Temperature	84.52 °F	Temperature	78.61 °F
Pressure	44.2 PSIG	Pressure	39.4 PSIG
APIb	41.8 °API	APIb	42.8 °API
Base Conditions	60 °F, 0 PSIG	Base Conditions	60 °F, 0 PSIG
Viscosity	5 cP	Viscosity	5 cP
Commodity Type	Crude	Commodity Type	Crude
Commodity Name/Grade	Oil Patch Medium	Commodity Name/Grade	Oil Patch Medium
Meter Factor (MF)	1.0042	Meter Factor (MF)	1.0050
MF Deviation	Tolerance	0.02 %	0.25 %
R%	Tolerance	0.031 %	0.050 %
MF Pass?	Run Pass?	YES	YES

# PROVER DATA

Manufacturer	Prover Maker	Model Number	Displacement	Serial Number	U-101
BPV	11.90482 bbls	Unidirectional	NO	GLp	0.00000620
OD	20.0000 in	Bidirectional	YES	GLD	N/A
ID	19.0000 in	Single Wall	YES	E	30,000,000
WT	0.5000 in	Double Wall	NO	Ball Displacer	YES
Barrel Material	Mild Carbon Steel	Internal Detectors	YES	Piston Displacer	NO
Rod Material	N/A	External Detectors	NO	Captive Displacer	NO

# FLUID DATA

Commodity Type	Crude Oil	API <sub>ind</sub>	44.2
Commodity Name/Grade	Oil Patch Medium	T <sub>obs</sub>	75.3
Physical Properties Reference	API MPMS Chapter 11.1	RHO <sub>obs</sub> (after HYC)	804.399 kg/m <sup>3</sup>
		RHO <sub>b</sub> (avg)	810.852 kg/m <sup>3</sup>

# PROVE CRITERIA

Meter Factor Method	Average Data				
Standard Deviation Method:	NO	Uncertainty:		Confidence	
Moving Range Method:	NO	Min # Runs:		Max # Runs:	
Fixed Range Method:	YES	# of Runs	5	Repeatability:	0.050 %

**Figure E.1a—Displacement Prover, Average Data, Fixed Range, Spot Sample**

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#### PROVING DATA

Run Number	N Pulses	Tp	Tm	Pp	Pm	BPH
3	11,852	78.62	78.67	39.6	44.3	4,000
4	11,851	78.23	78.54	39.1	44.4	4,000
5	11,850	78.56	78.82	39.2	44.6	4,000
6	11,852	78.83	78.91	39.6	44.9	4,000
7	11,849	78.82	78.93	39.4	44.2	4,000
<b>Average</b>	11,850.80	78.61	78.77	39.4	44.5	4,000

#### GSVp DETERMINATION

BPV	CTSp	CPSp	CTLp	CPLp	GSVp
11.90482	1.000346	1.000050	0.990315	1.000239	11.79701

#### ISVm DETERMINATION

N Pulses	NKF	IVm	CTLm	CPLm	ISVm
11,850.8	1,000	11.85080	0.990232	1.000271	11.73822

#### METER FACTOR DETERMINATION

GSVp /	ISVm =	MF
11.79701	11.73822	1.0050

#### WITNESSES

Signature		Date		Company	
Signature		Date		Company	
Signature		Date		Company	

**Figure E.1b—Displacement Prover, Average Data, Fixed Range, Spot Sample**



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# OPERATOR

# LOCATION

API MPMS Chapter 12.2	Midstream Metering Location
-----------------------	-----------------------------

# METER DATA

Meter ID Number:	300	MF, CMF, or KF	MF	MFG & Model	Co ABC, A100
Totalizer Reading:	2,342,501.02 BBLS	Meter Type	Turbine	Serial No.	TB-6822
Temp. Compensated	NO	Meter Size	8 in.	NKF	525.000
Press. Compensated	NO	Density Type	Densitometer	DMF	0.9998

# PREVIOUS PROVING REPORT

# CURRENT PROVING REPORT

Date	October 15, 2018	Date	November 19, 2018
Report Number	10	Report Number	11
Totalizer Reading	1,343,439.42 BBLS	Totalizer Reading	2,342,501.02 BBLS
Flow Rate	4,000 BPH	Flow Rate	4,000 BPH
Temperature	87.54 °F	Temperature	85.39 °F
Pressure	85.2 PSIG	Pressure	81.3 PSIG
APIb	60.1 °API	APIb	59.1 °API
Base Conditions	60 °F, 0 PSIG	Base Conditions	60 °F, 0 PSIG
Viscosity	5 cP	Viscosity	5 cP
Commodity Type	Gasoline	Commodity Type	Gasoline
Commodity Name/Grade	84RBOB	Commodity Name/Grade	84RBOB
Meter Factor (MF)	0.9972	Meter Factor (MF)	0.9968
MF Deviation	Tolerance	MF Deviation	Tolerance
	0.02 %		0.04 %
	0.25 %		0.25 %
R%	Tolerance	R%	Tolerance
	0.035 %		0.021 %
	0.050 %		0.050 %
MF Pass?	Run Pass?	MF Pass?	Run Pass?
	YES		YES
	YES		YES

# PROVER DATA

Manufacturer	Prover Maker	Model Number	Displacement	Serial Number	U-101
BPV	0.7109500 bbls	Unidirectional	YES	GLp	0.00000390
OD	20.0000 in	Bidirectional	NO	GLD	0.00000080
ID	17.0000 in	Single Wall	YES	E	28,000,000
WT	1.5000 in	Double Wall	NO	Ball Displacer	NO
Barrel Material	316L	Internal Detectors	NO	Piston Displacer	NO
Rod Material	Invar™	External Detectors	YES	Captive Displacer	YES

# PROVE CRITERIA

Meter Factor Method	Intermediate				
Standard Deviation Method:	NO	Uncertainty:		Confidence	
Moving Range Method:	NO	Min # Runs:		Max # Runs:	
Fixed Range Method:	YES	# of Runs	5	Repeatability:	0.050 %

# PROVING DATA

Run Number	N Pulses	RHOobs g/cc	Tdm	Pdm	RHObp kg/m³	Tp	Tm	TD	Pp	Pm	BPH
1	374.650	0.729202	85.51	81.1	741.614	85.41	85.42	75.11	81.0	84.2	4,000
2	374.579	0.728323	85.42	81.1	740.696	85.34	85.36	75.21	81.2	84.5	4,000
3	374.650	0.729543	85.38	81.3	741.886	85.39	85.37	75.23	81.5	84.1	4,000
4	374.613	0.729745	85.43	81.3	742.112	85.42	85.45	75.25	81.4	84.6	4,000
5	374.634	0.728972	85.36	81.2	741.310	85.38	85.36	75.19	81.3	84.7	4,000
Average					741.524	85.39			81.3		4,000

Figure E.2a—Captive Displacer Prover, Intermediate Factor, Online Density

#### GSVp DETERMINATION

Run Number	BPV	CTSp	CPSp	CTLp	CPLp	GSVp
1	0.7109500	1.000464	1.000033	0.982665	1.000678	0.6994468
2	0.7109500	1.000463	1.000033	0.982680	1.000683	0.6994603
3	0.7109500	1.000464	1.000033	0.982688	1.000681	0.6994653
4	0.7109500	1.000465	1.000033	0.982675	1.000680	0.6994560
5	0.7109500	1.000464	1.000033	0.982674	1.000682	0.6994560

#### ISVm DETERMINATION

Run Number	N Pulses	NKF	IVm	CTLm	CPLm	ISVm
1	374.650	525.000	0.7136190	0.982658	1.000705	0.7017378
2	374.579	525.000	0.7134838	0.982666	1.000710	0.7016141
3	374.650	525.000	0.7136190	0.982702	1.000703	0.7017678
4	374.613	525.000	0.7135486	0.982655	1.000707	0.7016678
5	374.634	525.000	0.7135886	0.982688	1.000710	0.7017328

#### METER FACTOR DETERMINATION

Run Number	GSVp /	ISVm =	IMF
1	0.6994468	0.7017378	0.996735
2	0.6994603	0.7016141	0.996930
3	0.6994653	0.7017678	0.996719
4	0.6994560	0.7016678	0.996848
5	0.6994560	0.7017328	0.996755
		<b>MF</b>	<b>0.9968</b>

#### WITNESSES

Signature		Date		Company	
Signature		Date		Company	
Signature		Date		Company	

**Figure E.2b—Captive Displacer Prover, Intermediate Factor, Online Density**

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# OPERATOR

# LOCATION

API MPMS Chapter 12.2	Midstream Marketing Terminal
-----------------------	------------------------------

# METER DATA

Meter ID Number:	400	MF, CMF, or KF	MF & CMF	MFG & Model	Co ABC, PD
Totalizer Reading:	7,452,678.22 BBLS	Meter Type	PD	Serial No.	PD-7752
Temp. Compensated	NO	Meter Size	4 in.	NKF	200 p/gal
Press. Compensated	NO	Density Type	Hydrometer		

# PREVIOUS PROVING REPORT

# CURRENT PROVING REPORT

Date		October 18, 2018		Date		November 18, 2018	
Report Number		10		Report Number		11	
Totalizer Reading		4,543,999.47 BBLS		Totalizer Reading		7,452,678.06 BBLS	
Flow Rate		700 GPM		Flow Rate		700 GPM	
Temperature		80.42 °F		Temperature		77.76 °F	
Pressure		44.6 PSIG		Pressure		44.2 PSIG	
APIb		34.8 °API		APIb		34.3 °API	
Base Conditions		60 °F, 0 PSIG		Base Conditions		60 °F, 0 PSIG	
Viscosity		5 cP		Viscosity		5 cP	
Commodity Type		Diesel Fuel		Commodity Type		Diesel Fuel	
Commodity Name/Grade		No. 2 Diesel		Commodity Name/Grade		No. 2 Diesel	
Before Calibration CMF		1.0014		Before Calibration CMF		1.0024	
After Calibration CMF		1.0002		After Calibration CMF		1.0001	
MF Deviation	Tolerance	0.16 %	0.25 %	MF Deviation	Tolerance	0.22 %	0.25 %
R%	Tolerance	0.019 %	0.020 %	R%	Tolerance	0.017 %	0.020 %
MF Pass?	Run Pass?	YES	YES	MF Pass?	Run Pass?	YES	YES

# PROVER DATA

Manufacturer	Prover Maker	Model Number	Atmos. Tank	Serial Number	T-2006
BPV	1000 gallons	Unidirectional	N/A	GLp	0.00000620
OD	96.0000 in	Bidirectional	N/A	GLD	N/A
ID	95.5000 in	Single Wall	YES	E	N/A
WT	0.2500 in	Double Wall	NO	Ball Displacer	N/A
Barrel Material	Mild Carbon Steel	Internal Detectors	N/A	Piston Displacer	N/A
Rod Material	N/A	External Detectors	N/A	Captive Displacer	N/A

# FLUID DATA

Commodity Type	Diesel	API <sub>ind</sub>	35.2 °API
Commodity Name/Grade	No. 2 Diesel	T <sub>obs</sub>	72.0 °F
Physical Properties Reference	API MPMS Chapter 11.1	RHO <sub>obs</sub> (after HYC)	847.864 kg/m <sup>3</sup>
		RHO <sub>b</sub> (avg)	852.576 kg/m <sup>3</sup>

# PROVE CRITERIA

Meter Factor Method	Average Meter Factor				
Standard Deviation Method:	NO	Uncertainty:		Confidence	
Moving Range Method:	NO	Min # Runs:		Max # Runs:	
Fixed Range Method:	YES	# of Runs	3	Repeatability:	0.020 %

**Figure E.3a—Tank Prover, Intermediate Factor, Fixed Range, Spot Sample**

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#### PROVING DATA

Run Number	Upper Scale	Lower Scale	BPV Adjusted	Tp	Tm	Pp	Pm	GPM
1	1001.700	0.200	1001.500	76.77	76.58	0.0	44.2	700
2	1001.500	0.300	1001.200	77.72	77.67	0.0	44.0	700
3	1001.600	0.200	1001.400	78.79	78.64	0.0	44.4	700
Average				77.76			44.20	700

#### GSVp DETERMINATION

BPVa	CTSp	CPSp	CTLp	CPLp	GSVp
1001.500	1.000312	1.000000	0.992271	1.000000	994.0695
1001.200	1.000330	1.000000	0.991832	1.000000	993.3499
1001.400	1.000350	1.000000	0.991338	1.000000	993.0733

#### ISVm DETERMINATION

Nm Pulses	NKFm	IVm	CTLm	CPLm	ISVm
200327	200	1001.635	0.992359	1.000320	994.2996
200296	200	1001.480	0.991855	1.000322	993.6428
200297	200	1001.485	0.991407	1.000324	993.2009

#### COMPOSITE METER FACTOR DETERMINATION

GSVp /	ISVm =	IMF
994.0695	994.2996	0.999767
993.3499	993.6428	0.999702
993.0733	993.2009	0.999872
	MF	0.9998
	Pnormal	44.2
	CPLnormal	1.0003
	CMF	1.0001

#### WITNESSES

Signature		Date		Company	
Signature		Date		Company	
Signature		Date		Company	

Figure E.3b—Tank Prover, Intermediate Factor, Fixed Range, Spot Sample

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OPERATOR	LOCATION
API MPMS Chapter 12.2	Midstream Metering Location

#### METER DATA

Meter ID Number:	400	MF, CMF, or KF	MF	MFG & Model	Co ABC, PD
Totalizer Reading:	1,642,509.00 BBLS	Meter Type	PD	Serial No.	PD-6865
Temp. Compensated	NO	Meter Size	10 in	NKF	1,000
Press. Compensated	NO	Density Type	Hydrometer		

#### PREVIOUS PROVING REPORT

#### CURRENT PROVING REPORT

Date	October 18, 2018	Date	November 18, 2018
Report Number	10	Report Number	11
Totalizer Reading	1,643,999.47 BBLS	Totalizer Reading	1,742,509.06 BBLS
Flow Rate	4,000 BPH	Flow Rate	4,000 BPH
Temperature	87.54 °F	Temperature	85.74 °F
Pressure	110.2 PSIG	Pressure	100.63 PSIG
APIb	30.9 °API	APIb	30.4 °API
Base Conditions	60 °F, 0 PSIG	Base Conditions	60 °F, 0 PSIG
Viscosity	5 cP	Viscosity	5 cP
Commodity Type	Crude	Commodity Type	Crude
Commodity Name/Grade	Oil Patch Medium	Commodity Name/Grade	Oil Patch Medium
Meter Factor (MF)	0.9996	Meter Factor (MF)	0.9993
MF Deviation	Tolerance 0.06 %	MF Deviation	Tolerance 0.03 %
R%	Tolerance 0.043 %	R%	Tolerance 0.017 %
MF Pass?	Run Pass? YES	MF Pass?	Run Pass? YES

#### MASTER METER DATA

Meter ID Number:	1423	MF, CMF, or KF	MF	Meter Model	CMMeter
Totalizer Reading:	1,742,509.00 BBLS	Meter Type	Coriolis	Serial No.	CM-6865
Temp. Compensated	NO	Meter Size	10 in	NKF	2,000
Press. Compensated	NO	Density Type	Hydrometer		

#### FLUID DATA

Commodity Type	Crude Oil	API <sub>ind</sub>	32.2
Commodity Name/Grade	Oil Patch Medium	T <sub>obs</sub>	85.3
Physical Properties Reference	API MPMS Chapter 11.1	RHO <sub>obs</sub> (after HYC)	863.253 kg/m <sup>3</sup>
		RHO <sub>b</sub> (avg)	873.171 kg/m <sup>3</sup>

#### PROVE CRITERIA

Meter Factor Method	Intermediate				
Standard Deviation Method:	NO	Uncertainty:		Confidence	
Moving Range Method:	YES	Min # Runs:	3	Max # Runs:	10
Fixed Range Method:	NO	# of Runs		Repeatability:	

#### PROVING DATA

Run Number	Nmm Pulses	Nm Pulses	Tmm	Tm	Pmm	Pm	BPH
1	22,852	11,433	85.82	85.77	100.6	120.3	4,000
2	22,154	11,085	85.73	85.64	100.1	120.4	4,000
3	22,850	11,432	85.66	85.72	101.2	122.6	4,000
Average			85.74		100.63		4,000

Figure E.4a—Master Meter, Intermediate Factor, Moving Range, Spot Sample

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#### GSVmm DETERMINATION

Nmm Pulses	NKFmm	MMF	CTLmm	CPLmm	GSVmm
22,852	2000	1.0001	0.988407	1.000510	11.30043
22,154	2000	1.0001	0.988447	1.000507	10.95567
22,850	2000	1.0001	0.988479	1.000513	11.30030

#### ISVm DETERMINATION

Nm Pulses	NKFm	IVm	CTLm	CPLm	ISVm
11,433	1000	11.43300	0.988429	1.000610	11.30760
11,085	1000	11.08500	0.988488	1.000610	10.96407
11,432	1000	11.43200	0.988452	1.000621	11.30700

#### METER FACTOR DETERMINATION

GSVmm /	ISVm =	IMF
11.30043	11.30760	0.999366
10.95567	10.96407	0.999234
11.30030	11.30700	0.999407
	<b>MF</b>	0.9993

#### WITNESSES

Signature		Date		Company	
Signature		Date		Company	
Signature		Date		Company	

**Figure E.4b—Master Meter, Intermediate Factor, Moving Range, Spot Sample**

## Annex F (informative)

### Repeatability Calculation Examples

Table F.1 shows an example of calculating repeatability using a fixed range with five consecutive runs and the average data method <sup>3</sup>:

**Table F.1—Consecutive Runs and the Average Data Method**

Run Number	N Pulses
1	12,234
2	12,232
3	12,237
4	12,237
5	12,233

$$R\% = \frac{12,237 - 12,232}{12,232} * 100 = 0.041\% \quad (F.1)$$

Table F.2 shows an example of calculating repeatability using a fixed range with five consecutive runs and the intermediate factor method <sup>3</sup>:

**Table F.2—Consecutive Runs and the Intermediate Factor Method**

Run Number	IMF
1	0.99321
2	0.99330
3	0.99337
4	0.99343
5	0.99319

Run Number IMF

$$R\% = \frac{0.99343 - 0.99319}{0.99319} * 100 = 0.024\% \quad (F.2)$$

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<sup>3</sup>The examples in this annex are for illustration purposes only. They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

## Annex G (informative)

### Random Uncertainty of a Meter Factor Determined by Multiple Run Sets

Methods for combining run sets, either by addition or averaging, are defined in API *MPMS* Chapter 4.8 [2]. Regardless of the reasons for the combination, care has to be taken when determining if the proving data meets the repeatability criterion for an acceptable proving.

A common repeatability criterion for intermediate meter factors used for custody transfer is 0.027 % at the 95 % confidence level. Industry experience has shown that failing this criterion usually means that there is some problem with the meter or the proving system, or both, that should be addressed promptly to minimize measurement error. API *MPMS* Chapter 13.3 demonstrates the equivalency of this standard and the range criteria of five runs agreeing to within 0.05 % and three runs agreeing to within 0.02 %. Range criteria was developed to be and is explained in the literature as an approximation to calculating sample standard deviation and was developed before the advent of electronic calculators. Standard deviation is onerous to calculate manually which is why using range criteria gained wide acceptance.

This annex accepts that a bidirectional prover is calibrated with a forward and reverse pass. Therefore, a round trip on a bidirectional prover is considered a single run (or single measurement).

The example <sup>4</sup> at the end of this annex shows two methods to calculate the uncertainty due to random effects of a meter factor determined by combining intermediate meter factors in various ways. One method is preferred, and the other is acceptable. Both methods ignore the combination of runs and use the individual runs. Both methods are discussed in detail in API *MPMS* Chapter 13.3. Also shown are four erroneous methods. The acceptable answers are highlighted in green, and the erroneous answers are highlighted in red. All calculations except the last ones are unrounded. The sample standard deviation and student t factor are from functions found in popular electronic spreadsheets. The calculations would be the same if the inputs were pulses instead of meter factors.

Preferred method—Calculate the random uncertainty using the individual measurements.

Acceptable (Range method)—Calculate the random uncertainty using the range of the individual measurements.

Observations and Conclusions:

- 1) Different grouping and theoretically correct calculations on these groups result in slightly different answers. This is because all statistical calculations are approximations and different ways to calculate the same statistic may return different results.
- 2) The incorrectly calculated uncertainties vary quite a bit from the correctly calculated uncertainties. This is because the calculations assume inputs of measurements. The combination of measurements as described above are not measurements and equations developed for measurements do not apply. Note that the combination of runs for this example smooths out the variability.
- 3) The uncertainty of each set of five is greater than the acceptability criterion of 0.027 % at a 95 % confidence level but considering all 15 factors as a group shows the uncertainty is much less than the criterion. This is the direct result of considering more runs.

Figure G.1 shows the results of uncertainty calculations in multiple run sets. In addition, common mistakes are shown when calculating uncertainty while averaging run sets.

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<sup>4</sup>This example is for illustration purposes only. It is not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.



				Individual		
				Factors	Summed	Average
	Set 1	Set 2	Set 3	Preferred	Incorrect	Incorrect
Set 1	1.0004	0.9996	1.0000		3.0000	1.000000
Set 2	0.9996	0.9999	1.0002		2.9997	0.999900
Set 3	0.9999	1.0002	1.0001		3.0002	1.000067
Set 4	1.0003	1.0002	0.9996		3.0001	1.000033
Set 5	0.9998	1.0004	0.9997		2.9999	0.999967
mean	1.00000	1.00006	0.99992	0.99999	2.99998	0.999993
sd	0.000339	0.000313	0.000259	0.000289	0.0001924	6.412E05
n	5	5	5	15	5	5
sqrt(n)	2.236	2.236	2.236	3.873	2.236	2.236
stand uncertainty	0.000152	0.000140	0.000116	0.000075	0.000086	0.000029
rel stand unc (%)	0.0152%	0.0140%	0.0116%	0.0075%	0.0029%	0.0029%
student t factor (0.95,dof)	2.776445	2.776445	2.776445	2.144787	2.776445	2.776445
rel unc at 95% conf level	0.042%	0.039%	0.032%	0.016%	0.008%	0.008%
				Acceptable	Incorrect	Incorrect
range	0.0008	0.0008	0.0006	0.0008	0.0005	0.0002
student t factor (0.95,dof)	2.776445	2.7764451	2.776445	2.14478669	2.7764451	2.7764451
sqrt(n)	2.236	2.236	2.236	3.873	2.236	2.236
D(n)	2.326	2.326	2.326	3.472	2.326	2.326
rel unc at 95% conf level	0.043%	0.043%	0.032%	0.013%	0.027%	0.009%

**Figure G.1—Multiple Run Set Scenarios with Uncertainty Calculations**

where:

- mean is determined per API *MPMS* Chapter 13.3;
- sd is the sample standard deviation as determined per API *MPMS* Chapter 13.3;
- n is the number elements in the set;
- student t factor is as determined in API *MPMS* Chapter 13.3;
- standard uncertainty is determined per API *MPMS* Chapter 13.3;
- relative standard uncertainty is determined per API *MPMS* Chapter 13.3;
- relative uncertainty at the 95 % confidence level is determined per API *MPMS* Chapter 13.3;
- the elements in the Range Method are explained in API *MPMS* Chapter 13.3.

## Bibliography

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- [2] API MPMS Chapter 4.8, *Operation of Proving Systems*
- [3] API MPMS Chapter 9, *Density Determination*
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- [9] API MPMS Chapter 11.2.4, *Temperature Correction for the Volume of NGL and LPG Tables 23E, 24E, 53E, 54E, 59E, 60E*
- [10] API MPMS Chapter 21.2, *Electronic Liquid Volume Measurement Using Positive Displacement and Turbine Meters*