Manual of Petroleum Measurement Standards
Chapter 12 – Calculation of Petroleum Quantities

Section 2——Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors

Ballot Draft 02-11-2019

Forward

This document consolidates Parts 1 through 3 of previous editions of Chapter 12.2 and presents standard calculations for metering petroleum fluids using flow meters such as turbine or displacement meters. Units of measure in this document are in International System (SI) and United States Customary (USC) units consistent with North American industry practices.

Contents

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. With the advent of IEEE standards and the predominance of 64-bit floating-point operations, additional calculation methods were desired by the petroleum industry. The implementation procedures presented in this Standard are designed to use current computer technology, simplify the associated arithmetic operations, and incorporate current API *MPMS* Chapter 11 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 in parallel 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 and the requirements of this Standard.

This Standard presents two methods for data acquisition:

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

In the Discrete Method, flow-weighted averages (however each average is determined) of temperature, pressure and density are used to correct the total actual volume at operating conditions for the entire ticket period, as measured by the flow meter and corrected by the meter factor, to what that total actual volume would be at standard temperature and pressure conditions for the entire ticket period. Thus, the total indicated volume for the entire ticket period is corrected by the meter factor to determine the total gross volume for the entire ticket period; and, then the total gross volume is corrected to the gross standard volume for the entire ticket period.

In the Continuous Method, the process variables of density, temperature and pressure are sampled every scan cycle and the indicated volume of the meter is determined for each scan cycle as well. In the Continuous Method, temperature, pressure and density are used to correct the total actual volume at operating conditions for each scan cycle period, as measured by the flow meter and corrected by the meter factor, to what that total actual volume would be at standard temperature and pressure conditions for each scan cycle period. Thus, the total indicated volume for any given scan cycle period is corrected by the meter factor to determine the total gross volume for that scan cycle period; and, then the total gross volume is corrected to the gross standard volume for that same given scan cycle period. The incremental gross standard volumes determined for each scan cycle or sampling period would be summed on an accumulative basis for the entire measurement or ticket period to yield the total gross standard volume for the entire batch.

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.

Volumetric 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.

When a ticket has been calculated by a flow computer using the Continuous Method, the reported data can be used to make a calculation comparison using the Discrete Method. When this is done, the flow-weighted average temperature, pressure and gross observed density is used to calculate the flow-weighted average base density. The discrimination levels of temperature, pressure and density should be the same as those reported on the Continuous Method report for comparison purposes. These two methods might yield slightly different results due to the different rounding routines employed and the way the data is acquired and processed.

Rounding or truncating initial and intermediate values in the Continuous Method has been eliminated.

Rounding will only be 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.

Chapter 12 – Calculation of Petroleum Quantities

Section 2 – Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volumetric Correction Factors

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 and/or errata).

API *MPMS* Chapter 4, *Proving Systems*

API *MPMS* Chapter 13.2, 1st Edition, November 1994, *Statistical Aspects of Measuring and Sampling—Methods of Evaluating Meter Proving Data*

API *MPMS* Chapter 13.3, 2nd Edition, December 2017, *Measurement Uncertainty*

3 Terms and Definitions

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

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.

Correction for temperature of steel (CTS) - Correction for changes in length, area or volume of a steel prover, tank, tank car or other vessel, due to changes in the steel temperature between its reference temperature and its operation or calibration temperature.

Flow computation device - An arithmetic processing unit with associated memory that accepts electrically converted signals representing input variables from a 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, SCADA, measurement accounting system, or tertiary device."

Gross volume (GV) - The actual volume of fluids at flowing temperature and pressure.

Gross standard volume (GSV) - The gross volume (GV) corrected to base temperature and pressure conditions.

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

Indicated standard volume (ISV) - The indicated volume (IV) corrected to base temperature and pressure.

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.

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.

K Factor - The number of pulses generated by the meter per gross unit volume.

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

Master meter factor (MMF) - A factor used to correct the indicated volume (IVmm) of the master meter at operating conditions to the gross volume (GVmm) of the master meter at operating conditions.

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

Meter factor (MF) - A factor 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 reading (MR) - The instantaneous display of the register on a meter head or in a flow computer.

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

Nominal K Factor (NKF) - The number of pulses generated or electronically manufactured by the meter per indicated unit volume.

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

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

Proving report number - A number that is uniquely assigned to a proving report.

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

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.

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.

Sampling period - The time between the retrieval of live input variables.

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

4 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.

4.1 Units

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

4.2 Pipe Dimensions

- ID Inside diameter
- OD Outside diameter
- WT Wall thickness

4.3 Liquid Density

- API API Gravity Scale, expressed in ºAPI, that is derived from Relative Density
- DEN Density in kilograms of mass per cubic meter (kg/m^3) 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
- RHOalt RHO Alternate, is the calculated density at the primary quantity device, such as PD, turbine, Coriolis, USM, at its operating temperature and pressure. This is also known in industry as RHOtp.

4.4 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
- Tobs Temperature of the fluid observed at the hydrometer or density meter
- Tp Temperature at the field prover
- Tp(avg) 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

4.5 Pressure

- Bar Units of pressure in bars
- kPa Units of pressure in kilopascals
- 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

4.6 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
- CTDW Correction for the effect of temperature differences in the water
- CTLm CTL for the meter during a meter provng, 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 Chapter 9 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

4.7 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 and/or pressure conditions
- 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

4.8 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 $_j$th 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.

5 Field of Application

5.1 Applicable Fluids

This standard applies to fluids that, for all practical purposes, are Newtonian, single-phase, and homogeneous 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 utilize 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.

5.2 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.

5.3 Defined Tolerances

A mathematical simulation of a random set of 1 million CTL and CPL combinations with a precision of 14 decimals was compared to the same dataset rounded to 6 decimals. The comparison varied by approximately 1 part in a million (0.0001 %).

While the mathematical simulation shows the best possible result between the two methods, extreme changes in temperatures and pressures may induce differences between the Discrete Method and the Continuous Method since the CTL and CPL calculations have a non-linear response to linear changes in temperature and pressure. To mitigate these induced differences, batches should be cut if flowing conditions significantly change. See Annex B for more information outlining some scenarios showing significance.

6 Uncertainty

Reference API *MPMS* Chapter 13.3.

7 Precision, Rounding and Averaging

7.1 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 format.

7.2 Precision and Rounding

7.2.1 Precision

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

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

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

Measurement tickets using calculations from an off-site calculation program, such as SCADA or DCS, may obtain different results than flow computers or other on-site calculation devices when utilizing the Continuous Method. This is due to differences in the precision between the communications protocols. In addition, the values being accessed from the on-site device may have been rounded to a specific precision before storage. If the precision of the communication protocol for the off-site device is less than 64-bit IEEE floating point, and the off-site device is intended to be used for fiscal calculations, then the Continuous Method shall be used. If the precision is the same, then either method is acceptable.

7.2.2 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 8 of this document. Due to the increased precision of correction factors, this document shall utilize standard rounding practices which involves round up if the digit is 5 or greater.

In keeping with the hierarchy of accuracies, these levels may vary with the different applications of measurement tickets, meter provings, and prover calibrations. There may be occasions, such as measurement reports, displays, data logs and communications, where rounding or truncating is performed at the end of a multiplication chain to meet a special need.

7.3 Averaging

7.3.1 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.

7.3.2 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 (DWA). It is essential that the calculation variables be sampled and weighted in a flow proportional manner so that high flow rates are not undersampled and low flow rates are not oversampled.

Averages on a quantity weighted basis are normally referred to as flow-weighted averages (FWA). The primary flow measurement quantity, whether gross volume or mass, 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. This provides assurance of unbiased FWA which allows a replication of the ticket quantities when audited.

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 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:

$$FWA = \frac{\sum_{j=1}^{n}[PV_j * GV_j]}{\sum_{j=1}^{n}[GV_j]}$$

Where:

PVj	=	value of the process variable sampled at the jth sample as j varies from 1 to n
GV_j	=	value of the incremental quantity of GV calculated at the $_j$th sample as $_j$ varies from 1 to n
Note:		the denominator represents the gross volume for the period

7.3.3 Arithmetic Mean (AM)

Arithmetic Mean (AM) shall be calculated by:

$$AM = \frac{\sum_{j=1}^{n}[PV_j]}{n}$$

Where: PV_j = value of the process variable at the $_j$th sample as $_j$ varies from 1 to n

8 Discrimination Levels and Discrimination Tables

In the tables that follow (Tables 1-9), the number of digits shown as (X) in front of the decimal point are for illustrative purposes only, and may have a value more or less than the number of (X) 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.

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, coefficients and meter proving calculations.

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. 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.

Table 1 – Liquid Density Discrimination Levels

	Discrete and Continuous Methods					
	Exact Discrimination Report			*Reporting Discrimination*		
	API	DEN (kg/m^3)	RD & g/cc	API	DEN (kg/m^3)	RD & g/cc
RHOind (For Hydrometer)	XXX.x	X XXX.x5	X.xxx x5	-	-	-
RHOind (For Other Density Devices)	-	-	-	XXX.xxx x	X XXX.xxx	X.xxx xxx
RHOb (For commodity pricing)	XXX.x	X XXX.x5	X.xxx x5	-	-	-
RHOobs, RHOalt	-	-	-	XXX.xxx x	X XXX.xxx	X.xxx xxx
RHOobsWA, RHObWA, RHOb(avg)	-	-	-	-	X XXX.xxx	X.xxx xxx

Table 2 – Dimensional Discrimination Levels

	Discrete and Continuous Methods	
Meter Prover	US Customary (inches)	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

Note: In the event conventional pipe measurements are less than these discriminations, trailing zeroes may be used to accommodate the above discrimination levels.

Table 3 – Temperature Discrimination Levels

	Tickets		**Proving**
	Discrete Method *Exact Descrimination*	**Continuous Method** *Reporting Descrimination*	**Discrete & Continuous Methods** *Exact Descrimination*
	(ºF)	**(ºF)**	**(ºF)**
Tb	XX.0	XX.0	XX.0
Tobs (For hydrometer use only)	XXX.x	-	XXX.x
Tp, Td, Tmm, Tdm, Tm	-	-	XXX.xx
Td(avg), Tdm(avg), Tm(avg), Tp(avg), Tmm(avg)	-	-	XXX.xx
TWA, TWAdm	XXX.xx	XXX.xx	-
	(ºC)	**(ºC)**	**(ºC)**
Tb	XX.0	XX.0	XX.0
Tobs (For hydrometer use only)	XXX.x5	-	XXX.x5
Tp, Td, Tmm, Tdm, Tm	-	-	XXX.xx5
Tdm(avg), Tm(avg), Tp(avg), Tmm(avg)	-	-	XXX.xx5
TWA, TWAdm	XXX.xx5	XXX.xx5	-

Table 4 - Pressure Discrimination Levels

	Tickets		**Proving**
	Discrete Method *Exact*	**Continuous Method** *Reporting*	**Discrete & Continuous Methods** *Exact*
	(PSI)	**(PSI)**	**(PSI)**
Pb, Pba, Pbg	XX.xxx	XX.xxx	XX.xxx
Pobs (For hydrometer use only)	X XXX.0	-	X 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	XX.0	XX.0	-
Pemm, Pep	-	-	XX.0
	(kPa)	**(kPa)**	**(kPa)**
Pb, Pba, Pbg	XXX.xxx	XXX.xxx	XXX.xxx
Pobs (For hydrometer use only)	XX.x	-	XX.xx
Pp, Pmm, Pdm, Pm	-	-	XX.xx
Pdm(avg), Pm(avg), Pp(avg), Pmm(avg)	-	-	XX.xx
PWA, PWAdm	XX.xx	XX.xx	-
Peb, Pedm, Pem	XX.x	XX.x	-
Pemm, Pep	-	-	XX.x
	(bar)	**(bar)**	**(bar)**
Pb, Pba, Pbg	X.xxx xx	X.xxx xx	X.xxx xx
Pobs (For hydrometer use only)	XX.xxx	-	XX.xxxx
Pp, Pmm, Pdm, Pm	-	-	XX.xxxx
Pdm(avg), Pm(avg), Pp(avg), Pmm(avg)	-	-	XX.xxxx
PWA, PWAdm	XX.xxxx	XX.xxxx	-
Peb, Pedm, Pem	XX.xxx	XX.xxx	-
Pemm, Pep	-	-	XX.xxx

Table 5 – Discrimination Levels of Coefficients of Thermal Expansion

	Discrete and Continuous Methods *Exact Discrimination*	
	Linear Coefficients (GL)	
Type of Steel	US Customary (per °F)	SI Units (per °C)
Mild Carbon	**0.000 006 20**	0.000 011 16
304 Stainless	0.000 009 61	**0.000 017 30**
316 Stainless	0.000 008 89	**0.000 016 00**
17-4PH Stainless	**0.000 006 00**	0.000 010 80
Invar™ Rod	**0.000 000 88**	0.000 001 44

Note: The user should validate the coefficient of thermal expansion for stainless steel from the prover manufacturer.
Note: The bolded values above were taken from the American Society of Metals (ASM) in 2013. The above values apply to temperature ranges from 0 – 100 °C.
Note: The values above were taken from the American Society of Metals (ASM) in 2013.
Note: Bold numbers are original defined numbers from the ASM. Other numbers are derived based on SI to US customary conversions and vice versa.

Table 6 – Modulus of Elasticity Discrimination Levels (E)

	Discrete and Continuous Methods *Exact Discrimination*		
	US Customary	SI Units	SI Units
	(psi)	(bar)	(kPa)
Mild Carbon Steel	30 000 000	2 068 000	206 800 000
304 Stainless Steel	28 000 000	1 931 000	193 100 000
316 Stainless Steel	28 000 000	1 931 000	193 100 000
17-4PH Stainless	28 500 000	1 965 000	196 500 000

Note: The values above were taken from the American Society of Metals (ASM) in 2013.

Table 7 – Correction Factor Discrimination Levels

	Tickets		**Proving**
	Discrete Method *Exact*	**Continuous Method** *Reporting*	**Discrete & Continuous Methods** *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
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	7 Significant Digits	7 Significant Digits

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.

Table 8a - Volume Discrimination Levels – US Customary Units

	Barrels			Gallons		
	Tickets		Proving	Tickets		Proving
	Discrete Method *Exact*	**Continuous Method** *Reporting*	**Discrete & Continuous Methods** *Exact*	**Discrete Method** *Exact*	**Continuous Method** *Reporting*	**Discrete & Continuous Methods** *Exact*
BPV, BPVa	-	-	Per Certificate	-	-	Per Certificate
SRu, SRl	-	-	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	-

Table 8b - Volume Discrimination Levels – SI Units

	m^3			liters		
	Tickets		Proving	Tickets		Proving
	Discrete Method *Exact*	**Continuous Method** *Reporting*	**Discrete & Continuous Methods** *Exact*	**Discrete Method** *Exact*	**Continuous Method** *Reporting*	**Discrete & Continuous Methods** *Exact*
BPV, BPVa	-	-	Per Certificate	-	-	Per Certificate
SRu, SRl	-	-	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	-

Table 9 – Pulse Discrimination Levels

	Discrete & Continuous Methods *Exact Discrimination*		
	N	Ni	N(avg)
Whole Pulse Applications	XX XXX.0	-	XX XXX.xx
Pulse Interpolation Applications	-	XX.xxx	XX.xxx xx

9 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 8 for commodity pricing and trading purposes.

RHOb shall not be used in any of the calculation routines.

10 Correction Factors

10.1 Overview

Calculations in this document are based on correcting the measured volume of the merchantable liquid to its volume at base conditions. Correction factors are provided to adjust the metered volume to base conditions, and to adjust for inaccuracies associated with the meter's performance. Correction factors shall follow the rounding and reporting discriminations outlined in Section 8.

10.2 Liquid Density Correction Factors

10.2.1 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 or other appropriate standards.

The appropriate methods for determining density are outlined in API *MPMS* Chapter 9. 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 (RHOind) to correct it to the observed density (RHOobs).

Users of hand-held or online density meters shall apply the Density Meter Factor (DMF) to the indicated density (RHOind) to correct it to the observed density (RHOobs).

RHOobs shall be used to calculate the flow weighted average observed density (RHOobsWA).

RHOobsWA shall be used to properly derive the flow weighted base density (RHObWA) for CTL calculations. The commodity pricing base density (RHOb) is RHObWA rounded.

For some fluids (pure hydrocarbons, chemicals, solvents, etc.), the base density is a constant value because of stringent manufacturing specifications.

10.2.2 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 (RHObWA) 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.

10.2.3 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 (Pe) 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 (Pe) as defined in their respective physical property standards.

The equilibrium vapor pressure (Pe) 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 one atmosphere.

Non-volatile fluids have equilibrium vapor pressures at base temperature that are at or below atmospheric pressure. For a non-volatile 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.

10.2.4 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.

10.2.5 Temperature and Pressure Compensated Meters

In some instances, a meter's 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, CTLm = 1.0

For meters that are providing a pulse output that already has CPL applied mechanically or electronically, CPLm = 1.0

10.3 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 32-bit floating registers, the use of a CCF is no longer required and has been removed from this Standard.

10.4 Correction for Sediment and Water (CSW)

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

$$CSW = 1 - \frac{\%S\&W}{100}$$

Where: % S&W = volume percent sediment and water present

10.5 Steel Correction Factors

10.5.1 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 and/or contraction of the steel in the prover shell due to the average prover steel temperature.

CPS corrects for pressure expansion and/or contraction of the steel in the prover shell due to the average prover liquid pressure.

10.5.2 Correction for the Effect of Temperature on Steel (CTS)

10.5.2.1 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 8 shall be used if the coefficient(s) of expansion is unknown.

10.5.2.2 CTS for Displacement Provers with Internal Detectors and Atmospheric Tank Provers

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:

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

10.5.2.3 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 displacement provers, the correction factor for the effect of temperature (*CTS*) shall be modified and calculated as follows:

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

10.5.3 Correction for the Effect of Pressure on Steel (CPS)

10.5.3.1 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 8 shall be used if the modulus of elasticity is unknown.

10.5.3.2 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:

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

$$ID = OD - (2*WT)$$

10.5.3.3 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, CPSp = 1.

10.6 K Factor (KF) and Nominal K Factor (NKF)

10.6.1 K Factor (KF)

K Factors (KF) were used in early applications of measurement using turbine meters. Before the advent of flow computers, which convert pulses to volumes electronically, pulses alone were totalized by a pulse counter and volumes were calculated manually. The pulse counter itself had no logic. It simply counted a pulse each time a blade tip passed the pickup coil and kept a running total. Some meters may use a volume per pulse configuration, which is the reciprocal of the K Factor.

10.6.2 Nominal K-Factor (NKF)

When flow computers came into being, it became possible to totalize gross and gross standard volumes in various volume units (e.g., gallons, barrels, cubic meters, liters etc.). This can sometimes be done by installing a unit volume per pulse driver; but, typically it is done by installing or configuring a Nominal K Factor in the flow computer, which is simply a fixed number of pulses per indicated unit volume. The actual K Factor is derived from the meter proving while the Nominal K Factor is simply a driver designation for the flow computer to use to calculate indicated volume units. While the metering system's flow computer starts out its life with a Nominal K Factor (selectively for each meter), the operator may change the NKF to a different value at a later date as long as the same value of NKF is used for both meter proving and associated measurement tickets.

The nominal K Factor (*NKF*) is used to determine the meter factor (*MF*), master meter factor (*MMF*), and composite meter factor (*CMF*). The original nominal K Factor (*NKF*) is a fixed value for a specific meter, determined by the manufacturer of the device and supplied with the new meter. This original nominal K Factor is established at the time of installation of the flow meter but might be changed at a later date by the operator. In any case, the same Nominal K Factor shall be used for meter proving and for totalizing volumes. Many installations use a nominal K Factor throughout the operating life of the meter to facilitate an audit trail for meter proving.

Meter manufacturers publish their "design" or "brochure" K Factors (pulses per unit volume) in brochures and specification sheets for the convenience of users in sizing meter provers. Sometimes the average or single point factory test result is stamped on the body of the meter. Both are often called nominal K Factors in common parlance. For purposes of operating metering systems and calculating meter factors, the Nominal K Factor (NKF) has a precise meaning apart from the above references. For that reason, the Nominal K Factor installed in a flow computer may or may not be equal to the "design" K Factor, the "brochure" K Factor, the K Factor stamped on the meter case or the K Factor written on a meter tag when shipped.

10.6.3 Scenarios Using K-Factors, Nominal K Factors and Meter Factors

With the development of flow computers and their use in metering systems, three (3) basic scenarios are used:

Scenario 1: Constant Nominal K Factor and Variable Meter Factor

Scenario 2: Constant Meter Factor of 1.0000 and Variable Nominal K Factor

Scenario 3: Original K Factor (without NKF and without MF)

10.6.4 Composite Factors

For fluids that are governed by API *MPMS* Chapter 11.2.1 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, API *MPMS* Chapter 12.2 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:

$$CMF = MF * CPLnormal$$

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 CPLnormal is calculated from an assumed normal operating pressure.

Following the same idea, a CTLnormal correction might be contemplated. However, CTLnormal shall not be applied because even a 0.2 ˚F variation would be significant.

11 Generalized Equations for Liquid Volume Determinations

11.1 General

The following equations will describe the general concepts used in the calculations of liquid volumes for measurement tickets.

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.

11.2 Determination of Indicated Volume (IV)

The IV is the change in meter reading.

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

$$IVx = \sum_{j=1}^{n}[\frac{Nx_j}{NKFx}]$$

Where:

IVx = IV, IVm, IVmm

Nx_j = Nv, N, Nm, Nmm, Ni, Nimm, at the $_j$th sample as $_j$ varies from 1 to n

NKFx = NKF, NKFm, NKFmm

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

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

$$IVx = MRc - MRo$$

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 = MRc – MRo 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 3689045.00 if truncated, and the remainder, 0.996851, 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 bi-directional 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.

11.3 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:

$$ISVx = \sum_{j=1}^{n} [IV_j * CTL_j * CPL_j]$$

Where:

ISVx = ISV, ISVm, ISVmm

IVj = IV at the jth sample as j varies from 1 to n

CTLj = CTL at the jth sample as j varies from 1 to n

CPLj = CPL at the jth sample as j varies from 1 to n

11.4 Determination of Gross Volume (GV)

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

$$GVx = \sum_{j=1}^{n} [IV_j * MF_j]$$

Where:

GVx = GV, GVm, GVmm

IV_j = IV at the jth sample as j varies from 1 to n

MF_j = MF at the jth sample as j varies from 1 to n

11.5 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:

$$GSVx = \sum_{j=1}^{n} [IV_j * MF_j * CTL_j * CPL_j]$$

Where:

GSVx = GSV, GSVm, GSVmm

IV_j = IV at the jth sample as j varies from 1 to n

MF_j = MF at the jth sample as j varies from 1 to n

CTLj = CTL at the jth sample as j varies from 1 to n

CPLj = 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 of 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.

$$GSVp = BPV * \#run * CTSp * CPSp * CTLp * CPLp$$

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:

$$GSVp = BPVa * CTSp * CPSp * CTLp * CPLp$$

$$BPVa = SRU - SRL$$

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

Note: 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.

11.6 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:

$$NSV = GSV * CSW$$

11.7 Determination of S&W Volume (SWV)

The sediment & 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:

$$SWV = GSV - NSV$$

12 Measurement Tickets

12.1 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 and continuous method.

Care shall be taken to ensure that all copies of a measurement ticket are legible. Proper fiscal procedures forbid making corrections or erasures on a measurement ticket unless the interested parties agree to do so and initial the ticket to that effect. Should a mistake be made, the ticket should be marked "VOID" and a new ticket prepared. The voided ticket should be attached to the new one to support the validity of the corrected ticket.

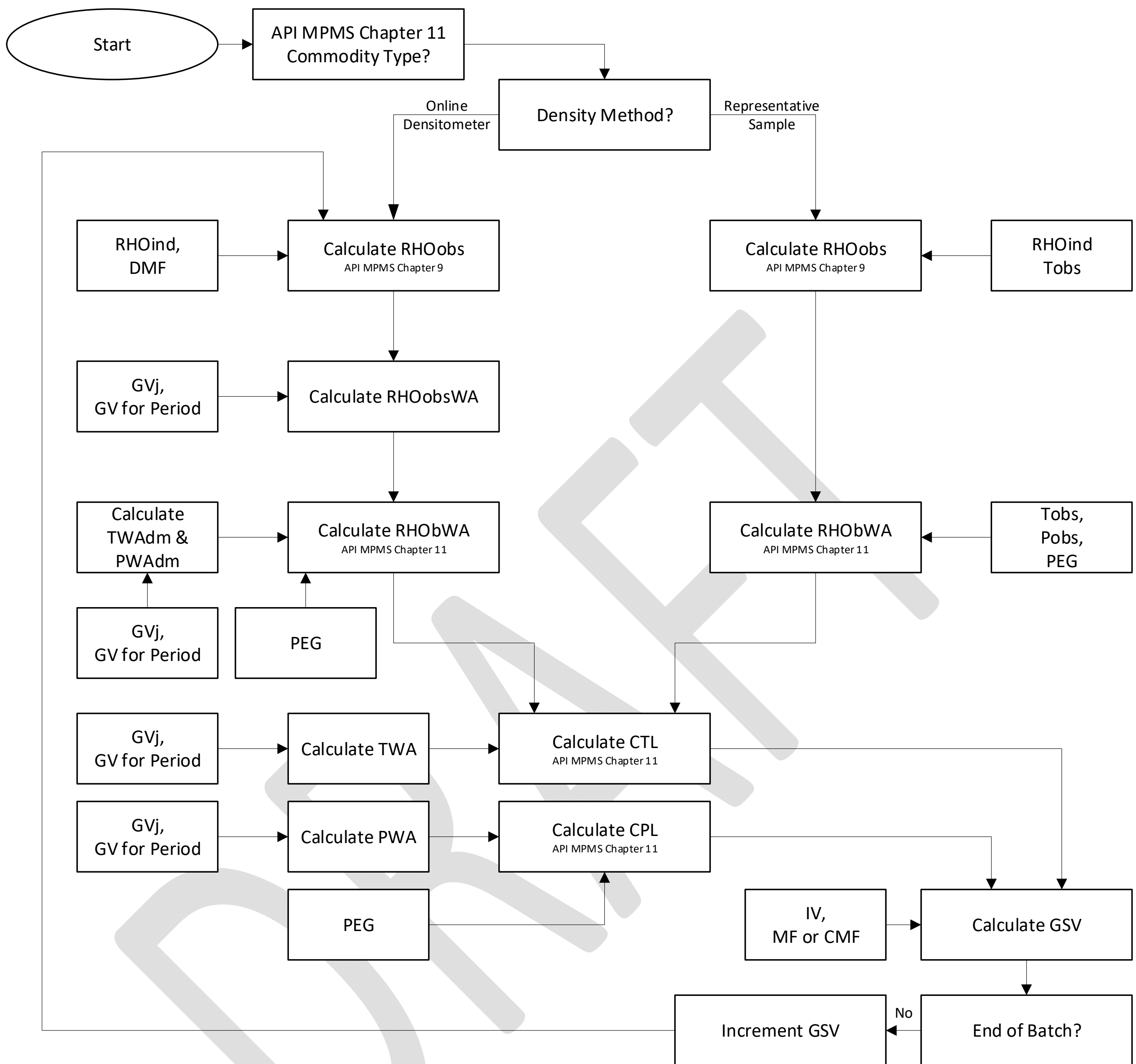
The Discrete or Continuous method should be selected between all connected parties and potentially legal regulation authorities for calculation of measurement tickets. The method selection should not vary between measurement tickets unless all parties agree to change methodology.

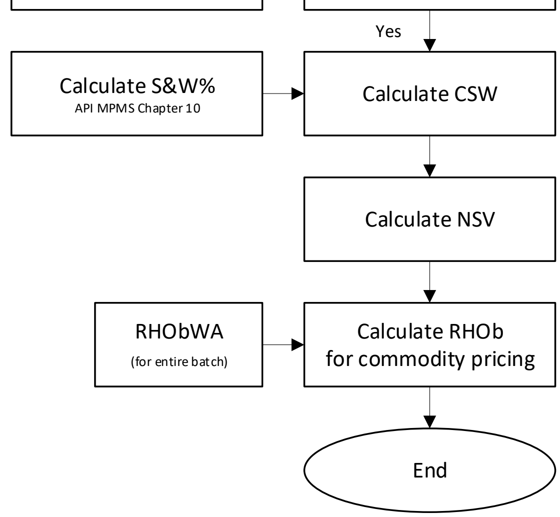
Example ticket calculations are included in Annex D. The examples may be used to aid in verifying procedures for any computer routines that are developed using the requirements stated.

12.2 Calculation Sequence Flow Chart

The flow chart 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 8.





Notes:

- 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.
- GVj and GV for period are considered to be the same measurement throughout the execution of this flow chart.
- RHOobsWA, RHObWA shall be an Absolute Density for flow averaging purposes. RHOWA, RHObWA shall not be calculated in API gravity.
- RHOb is RHObWA converted to the units the commodity is traded on and rounded.
- CTL = 1 for temperature compensated pulse trains.
- CPL = 1 for pressure compensated pulse trains or when a CMF is used.

13 Meter Proving Reports

13.1 Overview

Proving reports are written statements of the transfer of national metrological institute certifications to the meter. Proper measurement practices require that a proving report contain the field data required to calculate the meter factor or composite meter factor. If calculating a meter factor, the NKF and BPV shall be in the same volume units.

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.

Some custody transfers of liquid petroleum measured by meter are sufficiently small in volume or value, or are performed at essentially uniform conditions, that the meter can be mechanically and/or electronically adjusted to read within a predetermined accuracy. The use of these adjusted meters is determined between connected parties and potentially legal regulation authorities.

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.

Care shall be taken to ensure that all copies of a proving report are correct and legible. Standard procedure does not allow making corrections or erasures on a proving report. It shall be voided and a new meter proving report prepared.

13.2 Meter Factor & K Factor Calculation – Intermediate Factor and Average Data Methods

13.2.1 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 Section 13.3: The Average Data Method and the Intermediate Factor Method. 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 utilized 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.

13.2.2 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 Section 13.3. The intermediate meter factors are calculated from individual run process variables.

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

$$IMF = \frac{GSVx}{ISVx}$$

Where:

GSVx	=	GSVp, GSVmm
ISVx	=	ISVm, ISVmm

The meter factor is calculated as follows:

$$MFx = \frac{\sum_{j=1}^{n}[IMF_j]}{n}$$

Where:

MFx	=	MF, MMF
IMFj	=	Value of the IMF at the jth proving run as $_j$ varies from 1 to n
n	=	The number of consecutive proving runs

13.2.3 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 Section 13.3. The intermediate meter factors are calculated from individual run process variables.

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

$$IKF = \frac{N * CTLm * CPLm}{GSVx}$$

Where:

GSVx	=	GSVp, GSVmm

The K Factor is calculated as follows:

$$KFx = \frac{\sum_{j=1}^{n}[IKF_j]}{n}$$

Where:

KFx	=	KF, MKF
IKFj	=	Value of the IKF at the jth proving run as $_j$ varies from 1 to n
n	=	The number of consecutive proving runs

13.2.4 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 Section 13.3

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

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

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:

$$MFx = \frac{GSVx}{ISVx}$$

Where:

MFx	=	MF, MMF
GSVx	=	GSVp, GSVmm
ISVx	=	ISVm, ISVmm

13.2.5 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 Section 13.3

The average process variable for use in the K Factor calculation is calculated using an arithmetic mean as described in 7.3.3.

The K Factor is calculated as follows:

$$KFx = \frac{N(avg) * CTLm * CPLm}{GSVx}$$

Where:

KFx	=	KF, MKF
GSVx	=	GSVp, GSVmm

13.3 Evaluating Meter Proving Run Data

13.3.1 General

Meter proving run data shall be evaluated in accordance with the guidelines in API *MPMS* Chapter 13.2. 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. The dataset, used to evaluate the meter proving results, shall follow the criteria of the standards of API *MPMS* Chapter 4.

There are currently two practices which are acceptable for evaluating meter proving results. Calculating the standard deviation is the primary practice and 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, 1st 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, 2nd Edition, Equation 3. See also Annex E (and specifically the cautions) of API *MPMS* Chapter 13.3, 2nd 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.

13.3.2 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 to 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 utilized to calculate the range % for a set of data:

$$R\% = \frac{Maximum\ IMF - Minimum\ IMF}{Minimum\ IMF} * 100$$

$$R\% = \frac{Maximum\ IKF - Minimum\ IKF}{Minimum\ IKF} * 100$$

13.3.3 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 utilized to calculate the range % for a set of data:

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

13.3.4 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 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 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.

13.4 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.

A meter proving report is a written acknowledgement 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. The meter proving report shall contain all field data required to calculate the required factors of the meter.

Care shall be taken to ensure that all copies of a proving report are legible. Proper fiscal procedures forbid making corrections or erasures on a meter proving report unless the interested parties agree to do so and initial the report to that effect.

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

13.5 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:

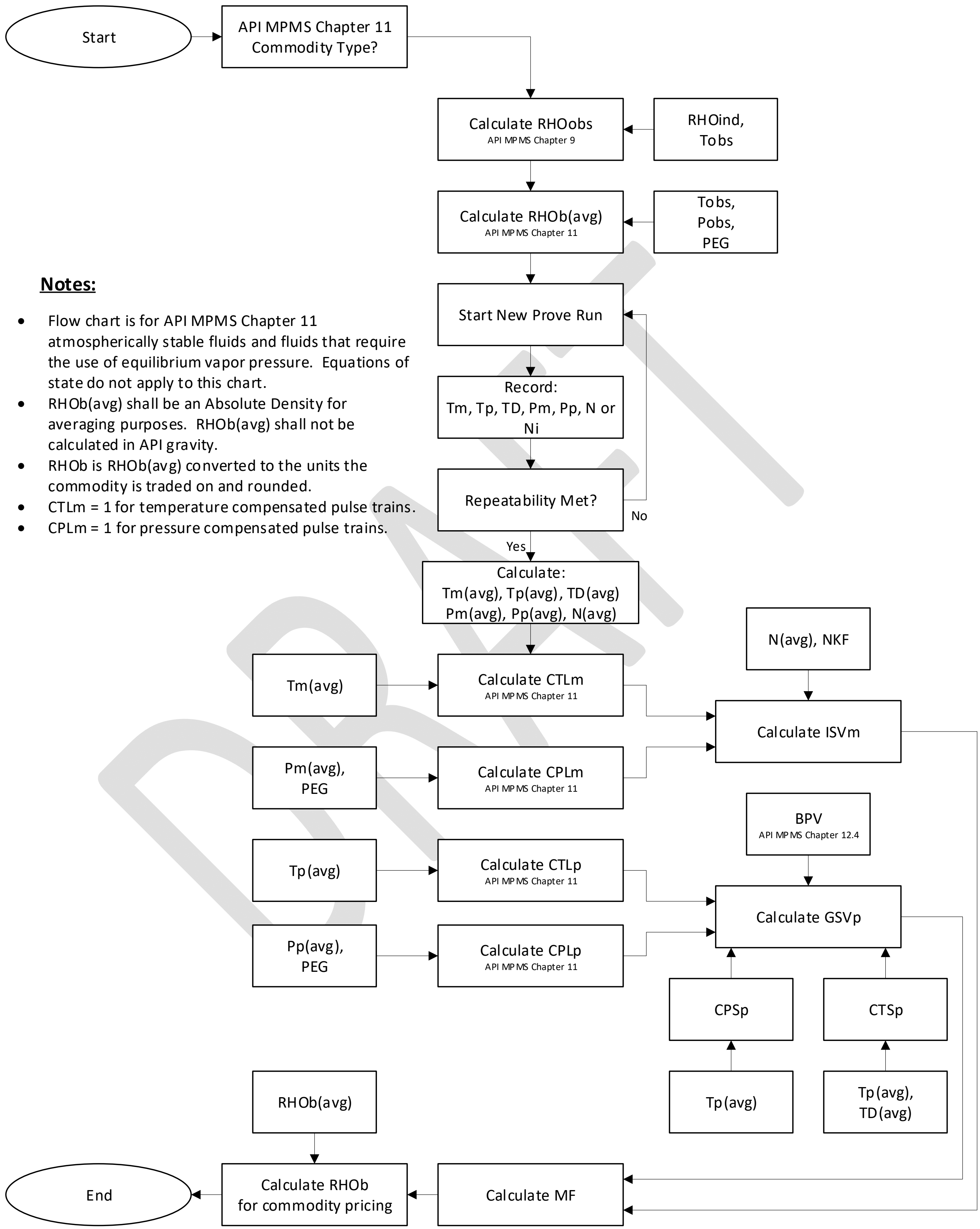
- Date of proving
- Proving report number
- Location identification
- Company assigned meter number
- Meter manufacturer, size, and model
- Meter serial number
- Flow rate at proving conditions
- Nominal K Factor
- Whether the meter pulse train is temperature compensated
- Whether the meter pulse train is pressure compensated
- The calculated factor that should 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

13.6 Calculation Sequences

13.6.1 – Calculation Sequence Displacement Provers with Average Data and Spot Sample



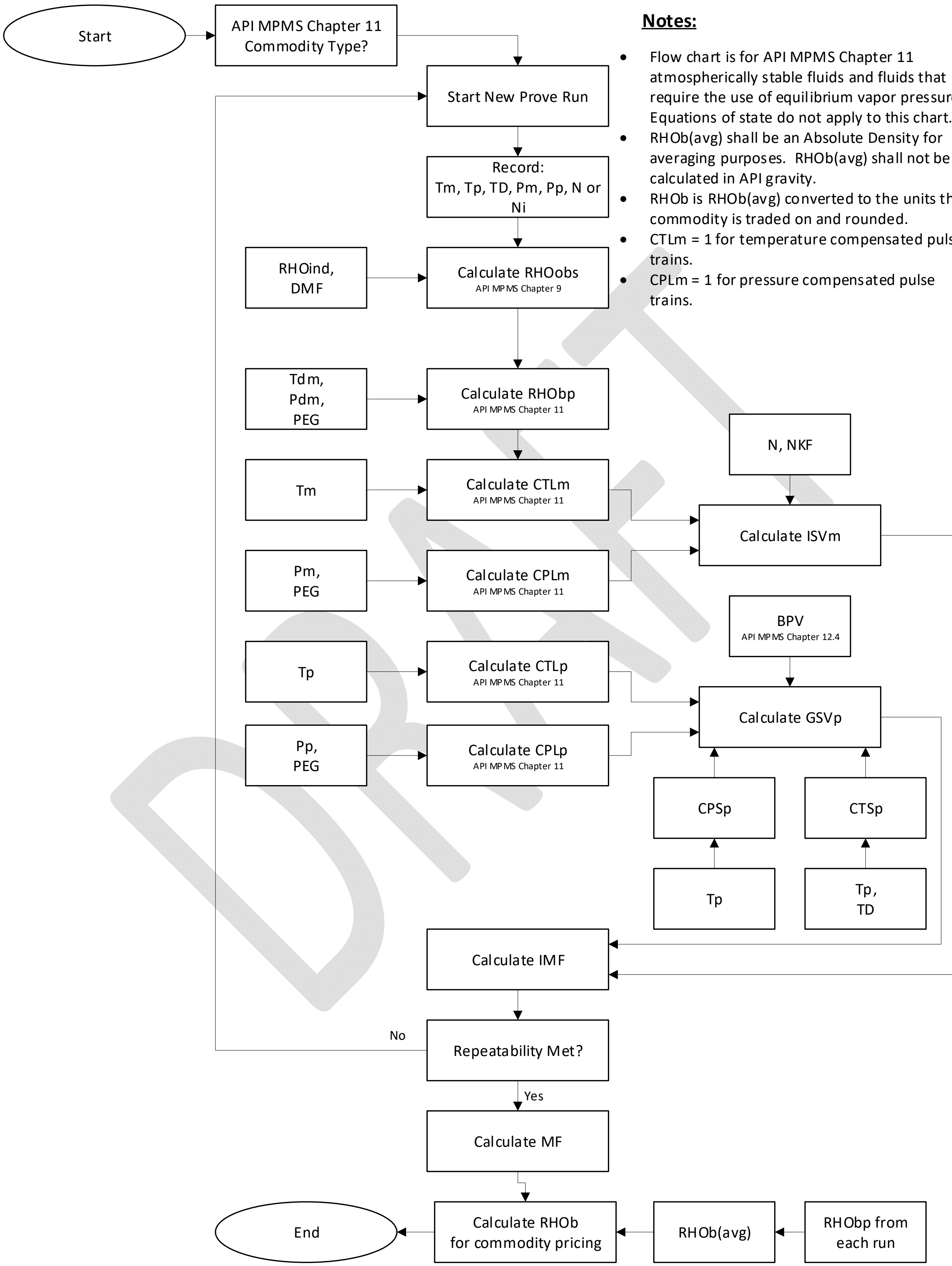
Notes:

- 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.
- RHOb(avg) shall be an Absolute Density for averaging purposes. RHOb(avg) shall not be calculated in API gravity.
- RHOb is RHOb(avg) converted to the units the commodity is traded on and rounded.
- CTLm = 1 for temperature compensated pulse trains.
- CPLm = 1 for pressure compensated pulse trains.

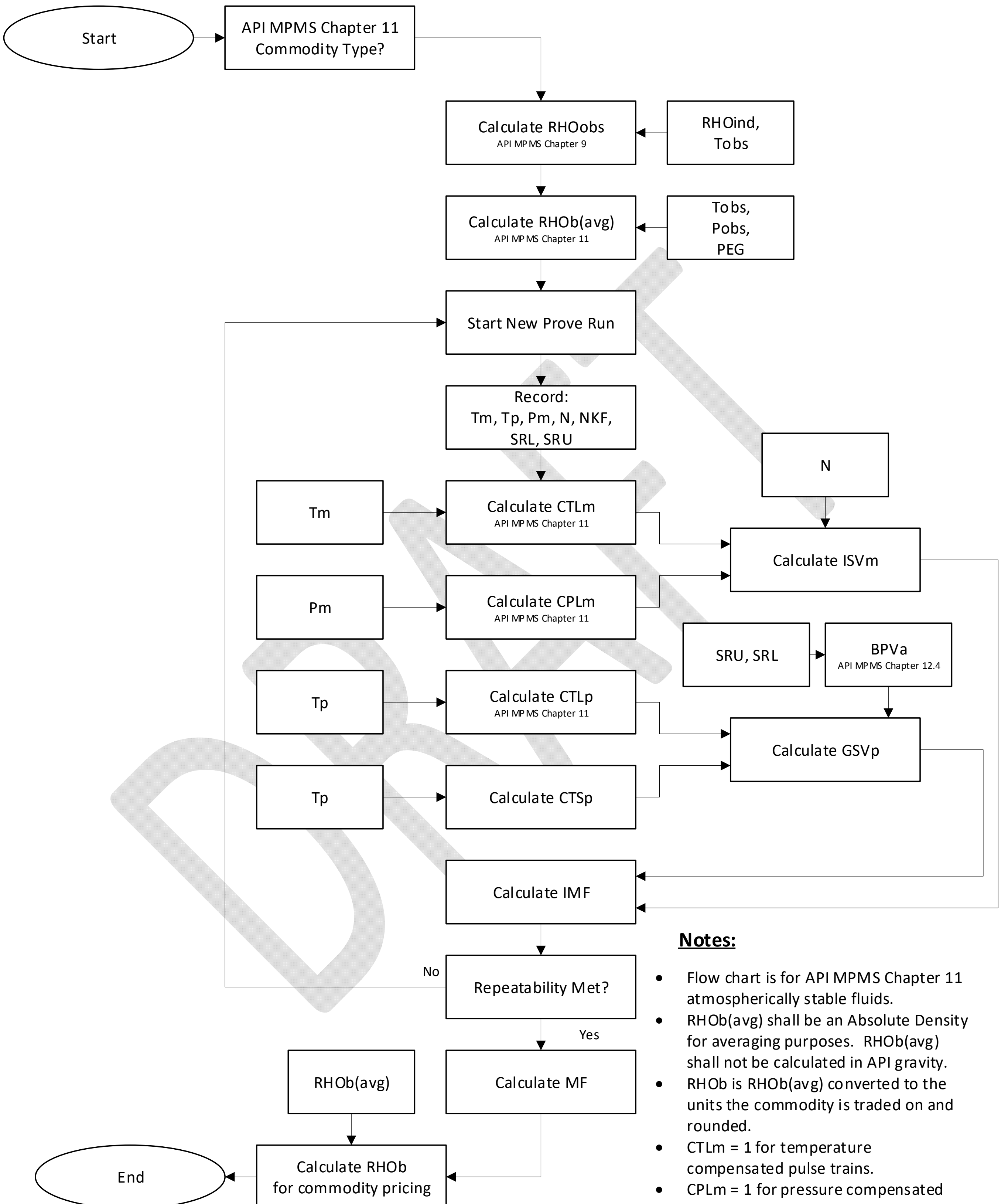
13.6.2 – Calculation Sequence Displacement Provers with Intermediate Factor and Online Densitometer

Notes:

- 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.
- RHOb(avg) shall be an Absolute Density for averaging purposes. RHOb(avg) shall not be calculated in API gravity.
- RHOb is RHOb(avg) converted to the units the commodity is traded on and rounded.
- CTLm = 1 for temperature compensated pulse trains.
- CPLm = 1 for pressure compensated pulse trains.



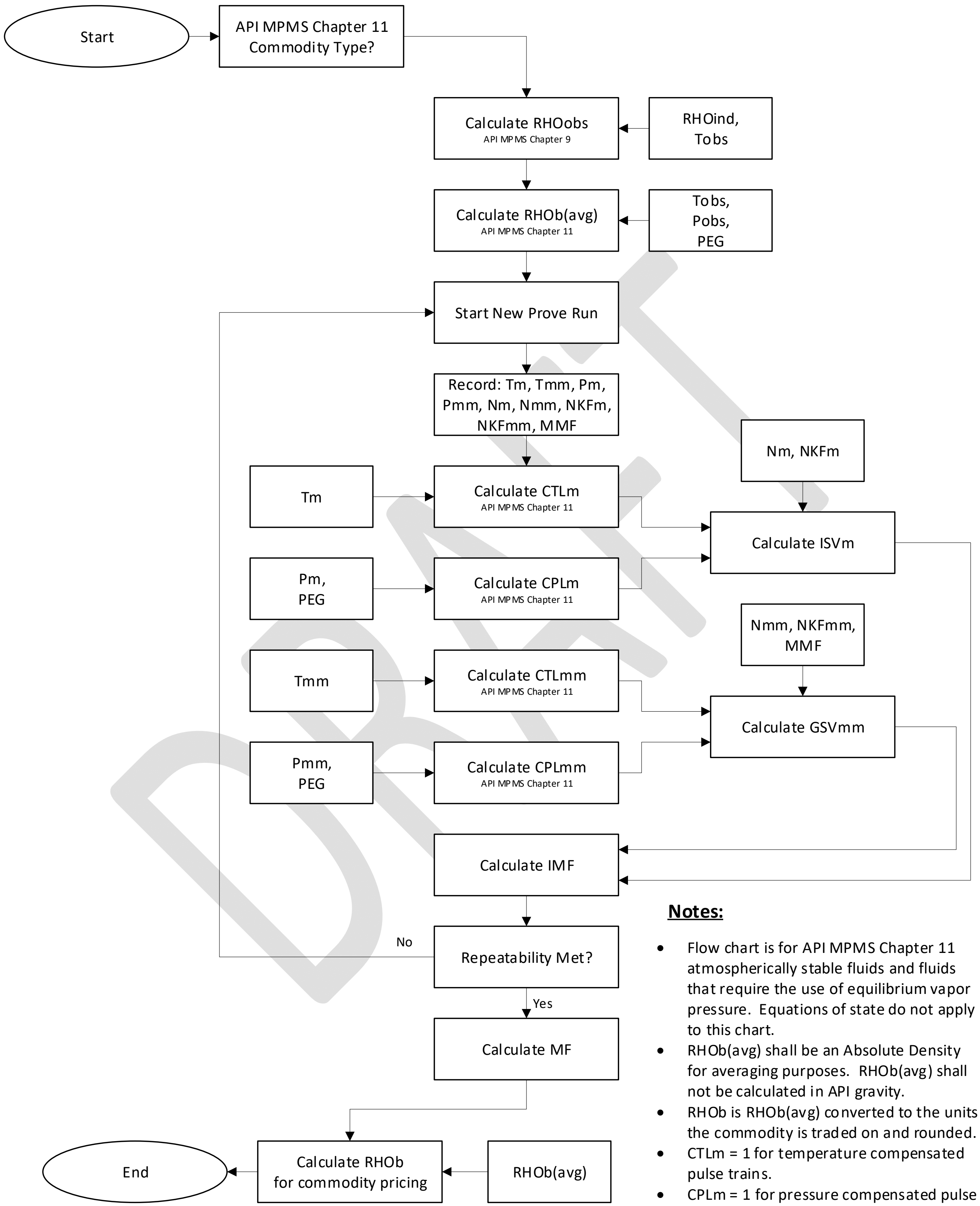
13.6.3 – Calculation Sequence Atmospheric Tank Provers with Intermediate Factor and Spot Sample



Notes:

- Flow chart is for API MPMS Chapter 11 atmospherically stable fluids.
- RHOb(avg) shall be an Absolute Density for averaging purposes. RHOb(avg) shall not be calculated in API gravity.
- RHOb is RHOb(avg) converted to the units the commodity is traded on and rounded.
- CTLm = 1 for temperature compensated pulse trains.
- CPLm = 1 for pressure compensated pulse trains.

13.6.4 – Calculation Sequence Master Meter Provers with Intermediate Factor and Spot Sample



Notes:

- 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.
- RHOb(avg) shall be an Absolute Density for averaging purposes. RHOb(avg) shall not be calculated in API gravity.
- RHOb is RHOb(avg) converted to the units the commodity is traded on and rounded.
- CTLm = 1 for temperature compensated pulse trains.
- CPLm = 1 for pressure compensated pulse trains.

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 in the following is not to provide the user of this document the exact definitions found elsewhere, but to provide assistance 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:

International System (SI) Units:

Pressure: 101.325 kPa (14.696 psia)

Temperature: 15.00°C (59.0°F)

International System (SI) Units:

Pressure: 101.325 kPa (14.696 psia)

Temperature: 20.00°C (68.0°F)

United States Customary (USC) Units:

Pressure: 14.696 psia (101.325 kPa_a)

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.

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

This annex demonstrates scenarios that were developed using physical flow computers setup in a laboratory environment. A positive displacement (PD) meter stack driven by a variable frequency drive motor, temperature transmitter setup in 4-20mA, and a pressure transmitter setup in 4-20 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 8 of this document. The table shows the comparison between the two methods.

		Discrete Method			Continuous Method					
Scenario	IV (bbl)	CTL	CPL	GSV (bbl)	GSV (bbl)	Delta (bbl)	%	Product	API	Temp (F)
1	257,831.32	0.989 288	1.000 333	255,154.37	255,152.72	-1.65	-0.000 646	Crude Oil	48	70-100
2	263,134.88	0.986 619	1.000 339	259,701.88	259,703.69	1.81	0.000 696	Crude Oil	48	70-100
3	235,367.64	0.989 244	1.000 333	232,913.56	232,914.59	1.03	0.000 442	Crude Oil	48	70-90
4	263,811.32	0.991 899	1.000 327	261,759.75	261,760.89	1.14	0.000 435	Crude Oil	48	70-80
5	240,285.75	0.986 066	1.000 456	237,045.65	237,046.63	0.98	0.000 413	Gasoline	65	70-90
6	239,877.88	0.957 402	1.000 512	229,777.15	229,763.48	-13.67	-0.005 949	Crude Oil	60	70-180
7	257,658.36	0.974 899	1.000 454	251,304.92	251,283.53	-21.39	-0.008 512	Crude Oil	60	40-120
8	257,244.80	0.978 511	1.000 336	251,801.44	251,788.04	-13.40	-0.005 323	Crude Oil	44	40-120

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 batch and cut batches accordingly or 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 would 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 illustrates how to calculate the density of the oil if there was no water present.

In this example, 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%

	APIb	RDb	gm/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 more dense than distilled water

$$RD_{mixture} = \frac{141.5}{131.5 + API_{mixture}}$$

$$Oil\% = 100\% - Water\%$$

$$RD_{oil} = \frac{RD_{mixture} - Water\% * RD_{water}}{Oil\%}$$

$$API_{oil} = \frac{141.5}{RD_{oil}} - 131.5$$

$$g/cc = RD * 0.999016$$

Annex D

Informative

Measurement Ticket Examples

The following examples have been provided to give guidance on the calculations that should be displayed on a measurement ticket:

D.1 – Crude Oil, Hydrometer, Meter Factor
D.2 – Gasoline, Densitometer, Meter Factor
D.3 – Jet, Hydrometer, Composite Meter Factor
D.4 – Diesel, Hydrometer, Temperature Compensated, Composite Meter Factor

These examples are not intended to be all inclusive as multiple other combinations of products, equipment configuration, and units exist.

The following examples are merely examples 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**.**

D.1 – Crude Oil, Hydrometer, Meter Factor

Midstream Metering Location
Meter Receipt

Ticket Nbr: 123456

Facility: Midstream Measurment
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:	0.9992
Pressure Compensated:	N	Density Type:	Glass Hydrometer
Factor Type:	MF	Density Factor:	N/A

Meter Reading Data:

Closing:	**300,000.00**	BBL	FWA Temperature (TWA):	**81.25**	°F
Opening:	**200,000.00**	BBL	FWA Pressure (PWA):	**152.2**	PSIG
Indicated:	**100,000.00**	BBL			

Fluid Properties Data:

Sample Gravity (APIind)	**45.2**	°API	FWA Density (RHOindWA)	**N/A**	
HYC Corrected Density (RHOobs)	**799.8913**	kg/m3	FWA Density (RHOobsWA)	**N/A**	
Obs. Pressure (Pobs)	**N/A**	PSIG	FWA Density Temperature (TWAdm)	**N/A**	
Obs. Temp (Tobs)	**71.0**	°F	FWA Density Pressure (PWAdm)	**N/A**	
S&W:	**0.2**	%	Equilibrium Vapor Pressure (PE)	**N/A**	PSIA

Calculations:

RHObWA: 804.564 kg/m3

IV	*	MF	*	CTL	*	CPL	=	GSV
100,000	*	0.9992	*	0.988763	*	1.000957	=	**98,891.75**
GSV	*	CSW	=	NSV				
98,891.75	*	0.99800	=	**98,693.96**				
GSV	-	NSV	=	SWV				
98,891.75	-	98,693.96	=	**197.78**				

Financial Ticketing Quantities:

GSV:	98,891.75	bbls
SWV:	197.78	bbls
NSV:	98,693.96	bbls
APIb:	44.2	°API

D.2 – Gasoline, Densitometer, Meter Factor

Ticket Nbr: 123456

Facility: Midstream Measurment
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 Factor:	0.9997

Meter Reading Data:

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

Fluid Properties Data:

Sample Gravity (APIind)	**N/A**	°API	FWA Density (RHOindWA)	**0.723234**	g/cc
HYC Corrected Density (RHObs)	**N/A**	kg/m3	FWA Density (RHOobsWA)	**723.017**	kg/m3
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:	**0.0**	%	Equilibrium Vapor Pressure (PE)	**N/A**	PSIA

Calculations:

RHObWA: 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

D.3 – Jet, Hydrometer, Composite Meter Factor

Midstream Metering Location
Meter Receipt

Ticket Nbr: 123456

Facility: Midstream Measurment
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 Factor:	N/A

Meter Reading Data:

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

Fluid Properties Data:

Sample Gravity (APIind)	**47.2**	°API	FWA Density (RHOindWA)	**N/A**	
HYC Corrected Density (RHOobs)	**790.887**	kg/m3	FWA Density (RHOobsWA)	**N/A**	
Obs. Pressure (Pobs)	**N/A**	PSIG	FWA Density Temperature (TWAdm)	**N/A**	
Obs. Temp (Tobs)	**76.0**	°F	FWA Density Pressure (PWAdm)	**N/A**	
S&W:	**0.0**	%	Equilibrium Vapor Pressure (PE)	**N/A**	PSIA

Calculations:

RHObWA: 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

D.4 – Diesel, Hydrometer, Temperature Compensated, Composite Meter Factor

Midstream Metering Location
Meter Receipt

Ticket Nbr: 123456

Facility: Midstream Measurment
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**	BBL	FWA Temperature (TWA):	**N/A**	°F
Opening:	**200,000.00**	BBL	FWA Pressure (PWA):	**N/A**	PSIG
Indicated:	**95,970.00**	BBL			

Fluid Properties Data:

Sample Gravity (APIind)	**37.5**	°API	FWA Density (RHOindWA)	**N/A**	
HYC Corrected Density (RHOobs)	**836.162**	kg/m3	FWA Density (RHOobsWA)	**N/A**	
Obs. Pressure (Pobs)	**N/A**	PSIG	FWA Density Temperature (TWAdm)	**N/A**	
Obs. Temp (Tobs)	**87.0**	°F	FWA Density Pressure (PWAdm)	**N/A**	
S&W:	**0.0**	%	Equilibrium Vapor Pressure (PE)	**N/A**	PSIA

Calculations:

RHObWA: 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

Annex E

Informative

Proving Report Examples

The following examples have been provided to give guidance on the calculations that should be displayed on a proving report:

E.1 – Displacement Prover, Average Data, Fixed Range, Spot Sample
E.2 – Captive Displacer Prover, Intermediate Factor, Fixed Range, Online Density
E.3 – Tank Prover, Intermediate Factor, Fixed Range, Spot Sample
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.

E.1 – Displacement Prover, Average Data, Spot Sample

OPERATOR	LOCATION
API MPMS Chapter 12.2	Midstream Metering Location

METER DATA

Meter ID Number:	200	MF, CMF, or KF	MF	Meter Model	PDMeter
Totalizer Reading:	1,642,509.00	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

Date		October 18, 2018	
Report Number		10	
Totalizer Reading		1,543,999.47	
Flow Rate		4,000 BPH	
Temperature		84.52 F	
Pressure		44.2 psig	
APIb		41.8 API	
Viscosity		5 cP	
Commodity Type		Crude	
Commodity Name/Grade		Oil Patch Medium	
Meter Factor (MF)		1.0042	
MF Dev	Tolerance	0.02%	0.25%
Run Dev	Tolerance	0.031%	0.050%
MF Pass?	Run Pass?	YES	YES

CURRENT PROVING REPORT

Date		November 18, 2018	
Report Number		11	
Totalizer Reading		1,642,509.06	
Flow Rate		4,000 BPH	
Temperature		78.61	
Pressure		39.4	
APIb		42.8	
Viscosity		5 cP	
Commodity Type		Crude	
Commodity Name/Grade		Oil Patch Medium	
Meter Factor (MF)		1.0050	
MF Dev	Tolerance	0.08%	0.25%
Run Dev	Tolerance	0.025%	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	0.0000062
OD	20.000 in	Bidirectional	YES	GLD	N/A
ID	19.000 in	Single Wall	YES	E	30,000,000
WT	0.500 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	APIind	44.2
Commodity Name/Grade	Oil Patch Medium	Tobs	75.3
Physical Properties Reference	API MPMS Chapter 11.1	RHOobs (after HYC)	804.399 kg/m3
		RHOb(avg)	810.852 kg/m3

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%

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
Average	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***	***CTLm***	***CPLm***	***ISVm***
11,850.8	1,000	0.990232	1.000271	11.73822

METER FACTOR DETERMINATION

GSVp /	***ISVm =***	***MF x***
11.79701	11.73822	**1.0050**

WITNESSES

Signature		Date		Company	
Signature		Date		Company	
Signature		Date		Company	

E.2 – Captive Displacer Prover, Intermediate Factor, Online Density

OPERATOR	LOCATION
API MPMS Chapter 12.2	Midstream Metering Location

METER DATA

Meter ID Number:	300	MF, CMF, or KF	MF	Meter Model	A100
Totalizer Reading:	2,342,501.02	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		Totalizer Reading		2,342,501.02	
Flow Rate		4,000 BPH		Flow Rate		4,000 BPH	
Temperature		87.54		Temperature		85.39	
Pressure		85.2		Pressure		81.3	
APIb		60.1		APIb		59.1	
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 Dev	Tolerance	0.02%	0.25%	MF Dev	Tolerance	0.04%	0.25%
Run Dev	Tolerance	0.035%	0.050%	Run Dev	Tolerance	0.021%	0.050%
MF Pass?	Run Pass?	YES	YES	MF Pass?	Run Pass?	YES	YES

PROVER DATA

Manufacturer	Prover Maker	Model Number	Displacement	Serial Number	U-101
BPV	0.710950 bbls	Unidirectional	YES	GLp	0.00000889
OD	20.000 in	Bidirectional	NO	GLD	0.00000088
ID	17.500 in	Single Wall	YES	E	28,000,000
WT	1.500 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	742.111	85.42	85.45	75.25	81.4	84.6	4,000
5	374.634	0.728972	85.36	81.2	741.072	85.38	85.36	75.19	81.3	84.7	4,000
Average					741.476	85.39			81.3		4,000

GSVp DETERMINATION

Run Number	*BPV*	*CTSp*	*CPSp*	*CTLp*	*CPLp*	*GSVp*
1	0.710950	1.000465	1.000034	0.982665	1.000678	0.699448
2	0.710950	1.000464	1.000034	0.982680	1.000683	0.699462
3	0.710950	1.000465	1.000034	0.982688	1.000681	0.699467
4	0.710950	1.000465	1.000034	0.982675	1.000680	0.699457
5	0.710950	1.000465	1.000034	0.982674	1.000682	0.699457

ISVm DETERMINATION

Run Number	*N Pulses*	*NKF*	*CTLm*	*CPLm*	*ISVm*
1	374.650	525.000	0.982658	1.000705	0.701738
2	374.579	525.000	0.982666	1.000710	0.701614
3	374.650	525.000	0.982702	1.000703	0.701768
4	374.613	525.000	0.982655	1.000707	0.701668
5	374.634	525.000	0.982688	1.000710	0.701733

METER FACTOR DETERMINATION

Run Number	*GSVp /*	*ISVm =*	*IMF x*
1	0.699448	0.701738	0.996737
2	0.699462	0.701614	0.996933
3	0.699467	0.701768	0.996721
4	0.699457	0.701668	0.996849
5	0.699457	0.701733	0.996757
		MF	***0.9968***

WITNESSES

Signature		Date		Company	
Signature		Date		Company	
Signature		Date		Company	

E.3 – Tank Prover, Intermediate Factor, Fixed Range, Spot Sample

OPERATOR	LOCATION
API MPMS Chapter 12.2	Midstream Marketing Terminal

METER DATA

Meter ID Number:	400	MF, CMF, or KF	MF & CMF	Meter Model	PD Meter
Totalizer Reading:	7,452,678.22	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		Totalizer Reading		7,452,678.06	
22Flow 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		APIb		34.3	
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 Dev	Tolerance	0.16%	0.25%	MF Dev	Tolerance	0.22	0.25%
Run Dev	Tolerance	0.019%	0.020%	Run Dev	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	96.000 in	Bidirectional	N/A	GLD	N/A
ID	95.500 in	0Single Wall	YES	E	N/A
WT	0.250 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	APIind	35.2 °API
Commodity Name/Grade	No. 2 Diesel	Tobs	72.0 °F
Physical Properties Reference	API MPMS Chapter 11.1	RHOobs (after HYC)	847.864 kg/m3
		RHOb(avg)	852.576 kg/m3

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%

PROVING DATA

Run Number	*Upper Scale*	*Lower Scale*	*BPV Adjusted*	*Nm Pulses*	*Tp*	*Tm*	*Pp*	*Pm*	*GPM*
1	1001.700	0.200	1001.500	200322	76.77	76.58	0.0	44.2	700
2	1001.500	0.300	1001.200	200218	77.72	77.67	0.0	44.0	700
3	1001.600	0.200	1001.400	200274	78.79	78.64	0.0	44.4	700
Average					77.76			44.20	700

GSVmm 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*	*CTLm*	*CPLm*	*ISVm*
200327	200	0.992359	1.000320	994.2996
200296	200	0.991855	1.000322	993.6428
200297	200	0.991407	1.000324	993.2009

COMPOSITE METER FACTOR DETERMINATION

GSVp /	*ISVm =*	*IMF*
994.0695	994.3016	*0.999767*
993.3499	993.6458	*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	

E.4 – Master Meter, Intermediate Factor, Moving Range, Spot Sample

OPERATOR	LOCATION
API MPMS Chapter 12.2	Midstream Metering Location

METER DATA

Meter ID Number:	400	MF, CMF, or KF	MF	Meter Model	PDMeter
Totalizer Reading:	1,642,509.00	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

Date		October 18, 2018	
Report Number		10	
Totalizer Reading		1,643,999.47	
Flow Rate		4,000 BPH	
Temperature		87.54	
Pressure		110.2	
APIb		30.9	
Viscosity		5 cP	
Commodity Type		Crude	
Commodity Name/Grade		Oil Patch Medium	
Meter Factor (MF)		0.9996	
MF Dev	Tolerance	0.06%	0.25%
Run Dev	Tolerance	0.043%	0.050%
MF Pass?	Run Pass?	YES	YES

CURRENT PROVING REPORT

Date		November 18, 2018	
Report Number		11	
Totalizer Reading		1,742,509.06	
Flow Rate		4,000 BPH	
Temperature		85.74	
Pressure		100.63	
APIb		30.4	
Viscosity		5 cP	
Commodity Type		Crude	
Commodity Name/Grade		Oil Patch Medium	
Meter Factor (MF)		0.9993	
MF Dev	Tolerance	0.03%	0.25%
Run Dev	Tolerance	0.017%	0.020%
MF Pass?	Run Pass?	YES	YES

MASTER METER DATA

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

FLUID DATA

Commodity Type	Crude Oil	APIind	32.2
Commodity Name/Grade	Oil Patch Medium	Tobs	85.3
Physical Properties Reference	API MPMS Chapter 11.1	RHOobs (after HYC)	863.253 kg/m3
		RHOb(avg)	873.171 kg/m3

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

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***	***CTLm***	***CPLm***	***ISVm***
11,433	1000	0.988429	1.000610	11.30760
11,085	1000	0.988488	1.000610	10.96407
11,432	1000	0.988452	1.000621	11.30700

METER FACTOR DETERMINATION

GSVmm /	***ISVm =***	***IMF x***
11.30043	11.30760	*0.999366*
10.95567	10.96407	*0.999234*
11.30030	11.30700	0.999407
	MF	**0.9993**

WITNESSES

Signature		Date		Company	
Signature		Date		Company	
Signature		Date		Company	

Annex F

Informative

Repeatability Calculation Examples

Example of calculating repeatability using a fixed range with five 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

$$R\% = \frac{12{,}237 - 12{,}232}{12{,}232} * 100 = 0.041\%$$

Example of calculating repeatability using a fixed range with five 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

$$R\% = \frac{0.99343 - 0.99319}{0.99319} * 100 = 0.024\%$$

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. 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 trial 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 and/or the proving system 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 bi-directional prover is calibrated with a forward and reverse pass. Therefore, a round trip on a bi-directional prover is considered a single run (or single measurement).

The example at the end of this annex shows two methods to calculate the uncertainty due to random effects of a meter factor determined by combining three sets of five trial factors. 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 fifteen factors as a group shows the uncertainty is much less than the criterion. This is the direct result of considering more runs.

	Set I	Set II	Set III	Individual Factors Preferred	Summed Incorrect	Average Incorrect
	1.0004	**0.9996**	**1.0000**		3.0000	1.000000
	0.9996	**0.9999**	**1.0002**		2.9997	0.999900
	0.9999	**1.0002**	**1.0001**		3.0002	1.000067
	1.0003	**1.0002**	**0.9996**		3.0001	1.000033
	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	6.412E-05
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%**

Where,

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

Bibliography

API *MPMS* Chapter 4.8, *Operation of Proving Systems*

API *MPMS* Chapter 9, *Density Determination*

API *MPMS* Chapter 11, *Physical Properties Data (Volume Correction Factors)*

API *MPMS* Chapter 11.1, (2004 ed) *Temperature and Pressure Volume Correction Factors for Generalized Crude Oils, Refined Products, and Lubricating Oils*

API *MPMS* Chapter 11.2.2, *Compressibility Factors for Hydrocarbons: 0.350-0.637 Relative Density (60 °F/60 °F) and -50 °F to 100 °F Metering Temperature*

API *MPMS* Chapter 11.2.2M, *Compressibility Factors for Hydrocarbons: 350-637 Kilograms per Cubic Meter Density (15 °C) and -46 °C to 60 °C Metering Temperature*

API *MPMS* Chapter 11.2.4, *Temperature Correction for the Volume of NGL and LPG Tables 23E, 24E, 53E, 54E, 59E, 60E*

API *MPMS* Chapter 21.2, *Electronic Liquid Volume Measurement Using Positive Displacement and Turbine Meters*