Mass Measurement of Natural Gas Liquids

GPA Standard 8182–12

API Manual of Petroleum Measurement Standards Chapter 14.7

FOURTH EDITION, APRIL 2012

ADOPTED AS TENTATIVE STANDARD, 1982
REVISED 1984, 1995, 2003, 2012

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Foreword

Measurement by mass is often preferred for chemical reactions and various processes where the mass ratios of components are of primary interest in effecting control of the operation.

Since the 1970's, the gas processing industry has recognized the importance of measuring mixed natural gas liquid (NGL) streams using mass measurement techniques. The volume at standard conditions of each component of an NGL mixture may be accurately derived from the mass measurement process because, unlike volumetric measurement, the mass measurement process is not sensitive to the effect pressure, temperature, intermolecular adhesion and solution mixing have on the measured stream.

Solution mixing and intermolecular adhesion occurs when smaller molecules fill in the spaces between the larger molecules in the solution. Temperature and pressure also affect the amount of shrinkage caused by solution mixing and intermolecular adhesion. Due to these behaviors, the sum of the volumes of individual components in their pure state is greater than the volume of the mixture.

Today, mass measurement systems are commonly used to measure NGL mixtures like raw make and ethane-propane mixes as well as specification ethane product. On the other hand, many propane, isobutane, normal butane and natural gasoline streams are measured using volumetric techniques. A number of industry-developed standards address the design, construction, operation and maintenance aspects of mass and volumetric measurement systems. Volumetric measurement depends on tables and correlations to correct the volume measured at flowing conditions to a volume at base conditions. The actual stream composition is important to both mass and volumetric techniques.

The Gas Processors Association (GPA) publishes specifications for some of the products resulting from natural gas processing and fractionation including commercial propane, HD-5 propane, commercial butane, and others. Many companies also have specifications describing, among other things, the compositional requirements of a particular product. Mass measurement is the recommended method of measurement for these mixtures.

These specification products rarely, if ever, are comprised of a single component. Instead, specification products are themselves a mixture of several components and the actual composition may vary somewhat over time as a function of plant operation. Solution mixing therefore occurs in specification products as well as in raw make. Industry developed tables and correlations address physical properties of certain specification products, within the limits of the research database. Volumetrically measured streams are then adjusted using these tables and correlations for temperature, pressure and density effects. Errors may result when performing these volumetric measurement adjustments if the composition of the stream does not match the compositions for which the volume correction tables and correlations were derived or due to uncertainties in the correlations themselves.

This standard was developed jointly by GPA Section H, Measurement and Product Handling, and the API Committee on Gas Fluids Measurement (COGFM). It is referenced by API as Chapter 14, Section 7 (14.7) of the API Manual of Petroleum Measurement Standards (MPMS). The participation of COGFM in developing this standard is gratefully appreciated and acknowledged.

Throughout this publication, the latest appropriate API and GPA Standards are referenced.

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Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

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Standard for Mass Measurement of Natural Gas Liquids

1 Scope

This standard serves as a reference for the selection, design, installation, operation and maintenance of single-phase dynamic liquid mass measurement systems that operate in the 351.7 kg/m^3 to 687.8 kg/m^3 (0.350 to 0.688 relative density at 60 °F) density range. The mass measurement systems within the scope of this document include inferred mass measurement, where volume at flowing conditions is combined with density at similar conditions to result in measured mass, as well as Coriolis mass measurement.

Liquids with density below 351.7 kg/m^3 and above 687.8 kg/m^3 (below 0.350 and above 0.688 relative density at 60 °F) and cryogenic fluids (colder than approximately –50.8 °F) are excluded from the scope of this document, but the principles described herein may apply to such streams.

NGL product should be analyzed to determine the mixture composition and the composition should be considered in determining the measurement methods and equipment to be used. It is especially important to use mass measurement whenever the range of molecular sizes is great, such as in high ethane content (more than 2 % to 5 % ethane) raw make, and when mixture composition is variable during the measurement period. It is less critical when the sizes of molecules in the mixture are similar, such as in the case of mixed butanes.

Sampling equipment and techniques are covered including standards for analytical methods used to determine the composition of the sampled product. Equations of state and correlations used to calculate the density of the product are discussed. The standard used to convert mass to equivalent liquid volumes of components is also discussed.

Equipment exists which uses diverse principles for measuring volume, sampling the product, and determining the composition and density of the product. This standard does not advocate the preferential use of any particular type of equipment. It is not the intention of this standard to restrict future development or improvement of equipment. The contracting parties to any agreement should mutually agree on the equipment to be used.

2 Normative References

The following referenced documents are indispensable for the application of this document, or provide additional information pertinent to mass measurement of natural gas liquids. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API *MPMS* Chapter 5.2, *Measurement of Liquid Hydrocarbons by Displacement Meters*

API *MPMS* Chapter 5.3, *Measurement of Liquid Hydrocarbons by Turbine Meters*

API *MPMS* Chapter 5.4, *Accessory Equipment for Liquid Meters*

API *MPMS* Chapter 5.6, *Measurement of Liquid Hydrocarbons by Coriolis Meters*

API *MPMS* Chapter 5.8, *Measurement of Liquid Hydrocarbons by Ultrasonic Flowmeters Using Transit Time Technology*

API *MPMS* Chapter 11.2.2, *Physical Properties Data—Compressibility Factors for Hydrocarbons*

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

API *MPMS* Chapter 12.2, *Calculation of Petroleum Quantities*

API *MPMS* Chapter 14.3, *Concentric, Square-edged Orifice Meters*

API *MPMS* Chapter 14.4, *Converting Mass of Natural Gas Liquids to Equivalent Liquid Volumes*

API *MPMS* Chapter 14.6, *Continuous Density Measurement*

API *MPMS* Chapter 14.8, *Liquefied Petroleum Gas Measurement*

GPA Standard 2145 [1], *Table of Physical Properties for Hydrocarbons & Other Compounds of Interest to the Natural Gas Industry*

GPA Standard 2174, *Obtaining Liquid Hydrocarbon Samples for Analysis by Gas Chromatography*

GPA Standard 2177, *Analysis of Natural Gas Liquid Mixtures Containing Nitrogen & Carbon Dioxide by Gas Chromatography*

GPA Standard 2186, *Method for the Extended Analysis of Hydrocarbon Liquid Mixtures Containing Nitrogen and Carbon Dioxide by Temperature Programmed Gas Chromatography*

GPA Standard 8173, *Method for Converting Mass of Natural Gas Liquids and Vapor to Equivalent Liquid Volumes*

GPA TP-27, *Temperature Correction for the Volume of NGL and LPG Tables 23E, 24E, 53E, 54E, 59E & 60E*

3 Terms, Definitions, and Abbreviations

For the purposes of this document, the following definitions apply.

3.1 Definitions

3.1.1
Density, Absolute
The mass of the substance occupying a unit volume at specified conditions of temperature and pressure and not affected by atmospheric buoyancy. Absolute Density is commonly expressed in units such as kg/m^3, g/cc, lb/gal or lb/ft^3.

3.1.2
Mass
An absolute measure of the quantity of matter.

3.1.3
Weight
The net force exerted on an object's mass as compared to a reference standard. In most situations, the net force is a combination of the earth's gravity and the buoyancy of the fluid surrounding the object. Weighing is defined as measuring the net force acting on an object's mass.

Therefore, quantities determined in this procedure shall be by mass rather than by weight. This should be accomplished through the use of procedures in API *MPMS* Ch. 14.6 by referral of weighing devices used to calibrate density meters to test weights of known mass. This referral or calibration is done in the same locality (and gravitational force) as the density meter location, eliminating the need of further correlation for variations in local gravitational force.

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[1] Gas Processors Association, 6526 E. 60th Street, Tulsa, Oklahoma 74145, www.gasprocessors.com.

Weight observations to determine fluid density shall be corrected for air buoyancy (commonly called weight in vacuum). Such observations can be used in conjunction with the calibration of density meters or for checking the performance of equation of state correlations. Procedures are outlined in API *MPMS* Ch. 14.6.

Volumes and densities of NGL products shall be determined at operating temperatures and pressures for mass measurement to eliminate temperature and compressibility corrections. However, equivalent volumes of components are often computed for the determined mass flow. These volumes will be stated at standard or base conditions as follows:

Standard or Base Conditions

Temperature: 15 °C (or 60 °F).

NOTE These standard temperatures are not equal. 15 °C is equal to 59 °F and 60 °F is equal to 15.56 °C.

Pressure: Higher of 101.325 kPa (14.696 psia) or product equilibrium vapor pressure at 15 °C (or 60 °F).

3.2 Abbreviations

For the purposes of this document, the following abbreviations apply.

ρ_f	indicated density at operating conditions;
DMF	density meter factor;
IM_m	indicated Coriolis meter mass;
IV	indicated meter volume at operating conditions;
MF_m	meter factor when the Coriolis meter is configured to indicate mass;
MF_v	meter factor (volumetric) at operating conditions;
Q_m	total mass.

4 Mass vs Volumetric Measurement—Accuracy and Precision Implications

High ethane mixtures of NGL products shall be measured using mass measurement techniques defined in this and other related industry standards to eliminate the bias due to solution mixing errors and to eliminate the uncertainty in the volumetric correction algorithms and tables. Mass measurement eliminates the substantial errors associated with the solution mixing effect on these streams and any stream that contains major components of widely varying molecular sizes. Note that volumes derived from mass measured quantities are greater than quantities measured on a volumetric basis for these streams.

Volumetric measurement is often considered to be acceptable for specification LPG products of relatively high purity, such as HD-5 propane, isobutane, normal butane, and natural gasoline products, which are essentially free of physically smaller molecules such as ethane. Solution mixing errors for these products may range from greater than 0.5 % for high-ethane HD-5 propane to negligible levels for heavy natural gasolines. Volumetric measurement has an additional uncertainty that the assumed compositions the algorithms or tables are based on may not match the stream being measured.

Mass measurement is also useful for high purity ethane, ethylene or propylene streams and may, in fact, be used for any NGL or LPG stream.

5 Mass Determination

Mass measurement is frequently obtained by the following dynamic measurement methods.

5.1 Direct Mass Measurement

5.1.1 In direct mass measurement processes, the meter factor is applied to the indicated mass measured by the meter.

$$Q_m = IM_m \times \mathrm{MF}_m \qquad (1)$$

5.1.2 Coriolis Meters—Coriolis meters used for mass measurement have an output in units of mass and do not require a density input to provide the mass quantity. Coriolis meters shall conform to API *MPMS* Ch. 5.6 for the service intended.

5.2 Inferred Mass Measurement

5.2.1 Inferred mass measurement requires the volume at flowing conditions and the density at the same flowing conditions to be multiplied together, using appropriate and consistent units of measurement.

$$Q_m = IV \times \mathrm{MF}_v \times \rho_f \times \mathrm{DMF} \qquad (2)$$

Care shall be taken to ensure that the DMF is applied only once to the indicated density value. If the density is determined at a temperature and pressure different from the temperature and pressure at which the volume was determined, then the flowing density shall be corrected to the temperature and pressure conditions at the volume meter. Common flow computer implementation methods apply the DMF to the flowing density prior to combining the corrected density with the IV and MF_v.

5.2.2 Displacement, Turbine, or Ultrasonic Meters—When using displacement, turbine or ultrasonic meters to determine volume at flowing conditions, refer to API *MPMS* Ch. 5.2, API *MPMS* Ch. 5.3, or API *MPMS* Ch. 5.8 respectively.

5.2.3 Coriolis Meters configured for Volumetric Measurement—Coriolis meters may be configured to provide the flowing volume at operating conditions and determine the inferred mass flow rate by multiplying this volume by the density at flowing conditions from the Coriolis meter or a separate density device or calculation.

NOTE This is not recommended since the measurement uncertainty is higher than using the mass output directly from the Coriolis meter.

5.2.4 The density at flowing conditions may be measured by a density meter or may be calculated using an appropriate equation of state. Density meters conforming to API *MPMS* Ch. 14.6 have lower uncertainty and are preferred over calculated densities.

5.3 Orifice Meters

5.3.1 Use API *MPMS* Ch. 14.3 to determine the volume at flowing conditions for inferred mass measurement.

5.3.2 The mass measurement equations in API *MPMS* Ch. 14.3 may be used to determine mass flow rates through a system more directly than the volumetric method discussed in 5.2.1. Orifice measurement is typically found in ethylene and purity ethane streams and in other dense phase fluid streams.

6 Density Determination

6.1 General

Significant errors can result from inaccuracies in temperature measurement, pressure measurement, recording and/ or integration. Products with lower relative density are generally more sensitive to inaccuracy from these influences.

The highest level of accuracy is required for products lower in the density range. See API *MPMS* Ch. 14.6, Figure 6 and Figure 7, to establish recommended uncertainty levels of temperature and pressure determination.

For inferred mass measurement, as discussed in Section 5, the density at operating conditions is required and may be determined by one of the following methods.

6.2 Measured Density

6.2.1 Measured density of products shall be determined using density meters installed and calibrated in accordance with API *MPMS* Ch. 14.6, or as otherwise agreed between the contracting parties.

6.2.2 Density meters or probes shall be installed as follows.

6.2.2.1 There shall be no interference between flow meter and density meter or probe which would adversely affect either the flow or density measurement.

6.2.2.2 Temperature and pressure differences between the fluid in the flow meter, the density measuring device, and calibrating devices shall be within specified limits for the fluid being measured and the mass measurement accuracy expected or required. (See API *MPMS* Ch. 14.6, 2nd Ed., 1991, Figure 6 and Figure 7). Insulation shall be provided when required.

6.2.2.3 Density meters may be installed either upstream or downstream of the primary flow device(s) in accordance with applicable standards, but shall not be located between flow conditioning devices and meters and shall not cause fluid to bypass the primary flow measurement device(s). The density meter shall measure a representative sample of the flowing stream. The sample is representative when its density matches the density at the primary flow device(s) in time and within pressure and temperature tolerances allowed in API *MPMS* Ch. 14.6. The preferred installation location for density meters is downstream of the primary flow device, however, an upstream installation may be used providing there is no effect on the flow profile at the flow meter and that the pressure and temperature differences are within the tolerances allowed in API *MPMS* Ch.14.6.

6.2.3 Density meter accuracy will be seriously affected by accumulation of foreign material from the flowing stream. This possibility should be considered in selecting density measurement equipment, determining mounting orientation, and in determining the frequency of density equipment calibration and maintenance. Accuracy of the data recording, transmission and computation equipment, and/or methods should also be considered in system selection. See API *MPMS* Ch. 14.6.

6.3 Empirical

Liquid density at flowing conditions may be calculated as a function of composition, temperature and pressure when use of measured density is not practical. The user should evaluate the stability of the composition relative to the analysis period and the uncertainty of the calculation results when selecting the empirical method.

Calculations of density at flowing conditions may be made by means of empirical correlations or by generalized equations of state. The empirical correlations are derived from fitting experimental data covering specific ranges of compositions, temperatures, and pressures and can be inaccurate outside these ranges. GPA TP-1 for ethane-propane mixes and GPA TP-2 and TP-3 for high ethane raw make streams are examples of such correlations.

Generalized equations of state have application for a wide variety of systems and do not have strict limitations regarding composition and physical conditions; however, empirical correlations are more accurate when applied to the specific systems for which they were derived. The Rackett Equation, the Starling-Han modification of the Benedict-Webb-Rubin Equation of State, and several modified Redlich-Kwong Equations of State (Soave, Mark V, Peng-Robinson) are examples.

It is the responsibility of the contracting parties to verify the validity and accuracy limits of methods considered for empirical density determination on the particular fluids to be measured.

6.4 Application in Time

The calculated or measured density should be applied in real time to the volume measured at the flow meter. This provides for the maximum mass measurement precision, i.e. the incremental volume of liquid measured corresponds in direct time relation to the density calculated or measured and precludes errors caused by flow irregularities or stoppages. However, it is common practice to use the composition of a sample taken continuously during the delivery period proportional to the quantity measured (flow proportional), and to use the average temperature and pressure for the delivery period. As compared with continuous density calculations, the uncertainty can be greater for density calculated from a composite sample at the average temperature and pressure measured during the delivery period.

7 Volumetric Measurement for Inferred Mass Determination

7.1 General

For inferred mass measurement as discussed in Section 5, the volume at flowing conditions shall be determined. This shall be accomplished using a measurement system of accuracy acceptable to the contracting parties. Industry standards have been established for orifice, displacement, turbine, ultrasonic, and Coriolis meters. Any such measuring system used should be installed in accordance with these industry standards; however any measurement system of suitable accuracy may be employed which is acceptable to the contracting parties and installed in accordance with best industry practice. Meters with temperature or pressure compensation of any type, such as those intended to correct flowing volumes to standard conditions, shall not be used with this procedure.

7.2 Displacement Meters

Displacement meters used for volumetric measurement in deriving total mass shall conform to recommendations in API *MPMS* Chapter 5.2 for the service intended. Temperature or pressure compensation devices shall not be used on these meters, and accessories used shall conform to recommendations in API *MPMS* Ch. 5.4.

7.3 Turbine Meters

Turbine meters used for volumetric measurement in deriving total mass shall conform to recommendations in API *MPMS* Ch. 5.3 for the service intended. Temperature or pressure compensation devices shall not be used on these meters, and accessories used shall conform to recommendations in API *MPMS* Ch. 5.4.

7.4 Ultrasonic Meters

Ultrasonic meters used for volumetric measurement in deriving total mass shall conform to recommendations in API *MPMS* Ch. 5.8 for the service intended. Temperature or pressure compensation devices shall not be used on these meters, and accessories used shall conform to recommendations in API *MPMS* Ch. 5.4.

7.5 Coriolis Meters

Coriolis meters used for volumetric measurement in deriving total mass shall conform to API *MPMS* Ch. 5.6 for the service intended. Temperature or pressure compensation devices to correct for the effect of temperature or pressure on the liquid shall not be used on these meters, and accessories used shall conform to recommendations in API *MPMS* Ch. 5.4. It is permissible to correct for the effect temperature and/or pressure have on changes in the flexibility of the oscillating tube(s) of the Coriolis meter.

7.6 Meter Proving

Turbine, displacement, ultrasonic and Coriolis meters shall be proved in accordance with API *MPMS* Ch. 4.8 and API *MPMS* Ch. 12.2. The proving device should be installed to minimize temperature and pressure variances between the prover and meter, preferably within the limits shown in Figure 6 and Figure 7 of API *MPMS* Ch. 14.6, 2nd Ed., 1991. Insulation from the volume meter through the density meter and prover will minimize operating condition differences and may provide stability between the measuring devices.

Meter factor determination shall use meter and prover temperatures and pressures recorded per discrimination levels listed in API *MPMS* Ch. 12.2. The prover temperature and pressure shall be used to correct the prover volume and the meter temperature and pressure shall be used to correct the meter volume to base conditions per API *MPMS* Ch. 12.2, using the volume correction factors determined per GPA TP-27/API *MPMS* Ch. 11.2.4, and API *MPMS* Ch. 11.2.2. Other pressure, temperature volume correction data applicable to the fluid being measured may be used as agreed upon by the contracting parties.

7.7 Measurement By Orifice

Volumetric measurement by orifice shall conform to API *MPMS* Ch. 14.3.

8 Sampling

Sampling shall be accomplished in a manner that yields a sample that is proportional to and representative of the flowing stream during the measuring interval.

Procedures as outlined in GPA Standard 2174 and API *MPMS* Ch. 14.8 shall be followed as applicable.

Products that have equilibrium vapor pressures above atmospheric pressure shall be maintained at a pressure where vaporization cannot occur within the on-line variable volume sample system or floating piston transportation containers.

Sample collection and transportation containers equipped with floating pistons shall maintain sample storage pressures above the higher of equilibrium vapor pressure or sampling pressure. When utilizing this type of equipment, adequate precautions shall be observed to allow for thermal expansion of the product so that excessive pressure or release of product does not occur.

Procedures for thorough mixing of samples shall be provided to insure that samples transferred to transportation cylinders and the following analyses obtained are representative of the flowing stream during the measured interval.

9 Sample Analysis

Depending upon the composition of the stream, liquid sample analysis shall follow appropriate chromatographic procedures described in GPA Standards 2177, and 2186 or other methods agreed upon by the contracting parties.

Where applicable, such as with NGL products, extended analysis may be required on a regular or periodic basis to accurately determine the molecular weight and the density of the hexanes plus fraction (or of the last significant fraction determined by agreement).

10 Conversion of Measured Mass to Volume

Conversion from measured product mass into equivalent volumes of components shall be in accordance with GPA Standard 8173 (API *MPMS* Ch. 14.4). In this procedure, a chromatographic analysis representative of the measured product is used to determine the mass of each individual component that comprised the total mass. The individual component masses are then converted to their respective equivalent liquid volumes at standard conditions using component density values from GPA Standard 2145.

Bibliography

[1] GPA TP-1, *Liquid Densities of Ethane, Propane and Ethane-Propane Mixtures*

[2] GPA TP-2, *Liquid Densities of High-Ethane Raw Make Streams*

[3] GPA TP-3, *A Model for the Precise Calculation of Liquefied Natural Gas Densities*

[4] GPA TP-15, *A Simplified Vapor Pressure Correlation for Commercial NGLs*

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