

CALCULATION OF NATURAL GAS LIQUID QUANTITIES

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INTRODUCTION

There is no substitute for well maintained, properly installed, and properly performing measurement equipment. Provisions for measurement equipment installation, operation, and maintenance deliver the raw data required for those dealing with natural gas liquids (NGLs) to transact business. Then, this raw data can be adjusted or converted to values suitable for transactions to take place and be accounted for.

To make these adjustments and conversions, it helps to know the desired results. Some measurement software applications require volume quantities. Others require mass. For many NGL applications, the preferred outcomes are liquid volumes of pure components. This is because most NGL's are eventually fractionated into pure products and market prices for these are readily available. Sometimes, the gas equivalent values are also useful for operations.

Knowing the starting point is equally important. The starting point can vary depending on the type of measurement. Different resources and applications provide for different means of measuring NGL's. Measurements can be made by mass or volumetrically.

MEASUREMENT BY VOLUME

When NGLs are measured volumetrically, the measured volume is converted to contract base conditions. The *API Manual of Petroleum Measurement Standards (MPMS)*, Chapter 12, 1996 Edition, provides guidance for this calculation process. Because NGLs are processed hydrocarbon liquids, they have no sediment or water in them. Therefore, Gross Standard Volumes (*GSV*) is equal to Net Standard Volumes (*NSV*). *GSV* is the volume indicated by the meter, corrected for the meter's performance and the conditions of the liquid. The corrections to the meter's indicated volume are grouped together into the Combined Correction Factor (*CCF*).

$$NSV = GSV = IV \times CCF \quad \text{(Equation 1)}$$

where:

NSV = Net Standard Volume
GSV = Gross Standard Volume
IV = Indicated Volume
CCF = Combined Correction Factor

The volume indicated by the meter is called the indicated volume (*IV*). *IV* is the ending or closing meter reading (*MR_c*) less the beginning or opening meter reading (*MR_o*). Stated in equation form:

$$IV = MR_c - MR_o \quad \text{(Equation 2)}$$

where:

IV = Indicated Volume
MR_c = Closing Meter Reading
MR_o = Opening Meter Reading

CCF is the product of two correction factors: the correction for the meter's performance (Meter Factor; *MF*) and the correction for the temperature and pressure of a liquid (*C_{TPL}*). The *C_{TPL}* factor converts the density (ρ_b) and volume of the liquid to base conditions.

$$CCF = C_{TPL} \times MF \quad (\text{Equation 3})$$

where:

- CCF* = Combined Correction Factor
- C_{TPL}* = Correction for the Temperature and Pressure of the Liquid
- MF* = Meter Factor

According to Chapter 12 of the API *MPMS*, the meter factor (*MF*) is "a non-dimensional value which corrects a volume as indicated on a meter to the 'true' volume."¹ It is "a number obtained by dividing the actual volume of liquid passed through a meter during proving by the volume registered by that meter."²

The other term of the *CCF* equation is the factor to correct the volume or density for the temperature and pressure of the liquid (*C_{TPL}*). *C_{TPL}* is sometimes called a volume correction factor (*VCF*). It is separated into two calculations; one for the effect of the temperature (*C_{TL}*) and one for the effect of the pressure (*C_{PL}*) on the liquid.

$$C_{TPL} = C_{TL} \times C_{PL} \quad (\text{Equation 4})$$

where:

- C_{TPL}* = Correction for the Temperature and Pressure of the Liquid
- C_{TL}* = Correction for the Temperature of the Liquid
- C_{PL}* = Correction for the Pressure of the Liquid

The formula to calculate *C_{TL}* is beyond the scope of this paper. It is a fairly complex equation of state calculation which is described in the API *MPMS*, Chapter 11, Section 2, Part 4. It is a function of the liquid's density and temperature. It corrects the volume of the liquid from one temperature to another; the observed or measured temperature to the base temperature.

For most, if not all, transactions in the United States, hydrocarbon liquid volumes are converted to 60°F for transaction purposes. This is important for evaluating NGLs. There is a difference in the value of a barrel of NGL at 60°F and the value of a barrel of the same NGL at 70°F. The barrel of NGL at 60°F is more valuable because when the NGL at 70°F is allowed to cool to 60°F, it will be less than a barrel in volume. Heat causes hydrocarbon liquids to expand. The difference in volume caused by temperature, especially with lighter NGLs, may be several percent. With large volumes or long periods of time, the difference in money can become very large.

Likewise, pressure has an effect on the volume of a hydrocarbon liquid. As more pressure is applied, the liquid is compressed. The effect on the volume by small changes in pressure is not as much as small changes in temperature.

C_{PL} is a function of the liquid's pressure, temperature, and density. Although still beyond the scope of this paper, the calculation of *C_{PL}* is less complex than *C_{TL}*. The formula for calculating *C_{PL}* can be found in API *MPMS*, Chapter 11, Section 2, Part 2. For NGLs with a relative density greater than 0.637 (60°F/60°F), some believe the formula for Part 2 should be extrapolated. Others believe the *C_{PL}* calculation in API 11.1 should be used. Depending on the application, one equation may be more accurate than the other. In every case and as necessary, the interested parties should agree how volume corrections for the effects of pressure should be handled.

While base temperatures may vary across nations and communities, base pressure for liquid hydrocarbons is very common. Base pressure is the greater of atmospheric pressure or the liquid's saturation pressure. Saturation pressure is the pressure

¹ API Manual of Petroleum Standards, Chapter 12, Section 2, Page 2

² API Manual of Petroleum Standards, Chapter 12, Section 2, Page 11

exerted by a vapor in thermodynamic equilibrium with the condensed phase of the same substance at a given temperature in a closed system. Other names for this fluid property are equilibrium pressure, equilibrium vapor pressure, vapor pressure, or bubble point.

With the desired results in mind, all of the raw data can be adjusted and converted to get the Net Standard Volume. Without guidelines for the sequence of calculations and rounding of intermediate values, different *NSV*s can be calculated from the same input data.

In addition to the rounding guidelines in Chapter 11, API *MPMS* Chapter 12. 1996 Edition provides guidance on rounding, as well as the discrimination levels of input, intermediate, and final values, which depend on the device, the factor, and the units of measurement. Consistent use of the standard will provide consistent results across measurement systems. A typical sequence for a dynamic volume calculation is:

1. Determine the density of the liquid at base conditions (ρ_b ; base density); a function of the liquid's composition or the liquid's observed density, temperature, and pressure
2. Determine the Correction for the Temperature and Pressure of the Liquid (C_{TPL}); a function of the liquid's temperature, pressure, equilibrium vapor pressure, and base density
3. Determine the Combined Correction Factor (CCF) using Equation 3
4. Determine the Indicated Volume (IV) using Equation 2
5. Determine the Gross Standard Volume (GSV) using Equation 1
6. Determine the Net Standard Volume (NSV) using Equation 1

MEASUREMENT BY MASS

Although it can be useful to measure NGLs by volume, there are many uncertainties. The Correction for the Temperature of the Liquid (C_{TL}) is based on the density of the NGL. Density is not a very precise parameter to represent a potentially wide range of NGL compositions. Different mixtures behave differently. But if they have the same density, they are treated alike for C_{TL} calculations. Without composition information and consideration for volume shrinkage due to molecular mixing, it is more difficult to predict precise changes in volume due to changes in temperature. The current standard for correcting NGL volumes for temperature, API 11.2.4 (GPA TP-27), is based on an array of only 12 reference fluids, only three of which are mixtures. These three mixtures are binary, which means they have two components; one mixture of ethane and ethylene and two mixtures of ethane and propane. Nine pure products and three binary mixtures is not a very broad range of reference data to formulate calculations for the wide array of combinations of hydrocarbons which make up typical NGL mixtures.

Additional uncertainty in the *NSV* results from the calculation of the Correction for the Pressure of the Liquid (C_{PL}). C_{PL} is based on the difference between the liquid's measured pressure and its saturation pressure. Unless measured, a common method for determining a fluid's saturation pressure is presented in API *MPMS* Chapter 11.2.5. As with C_{TL} , this standard is based on a liquid's density, neglecting its composition. The standard acknowledges errors of more than 40% for natural gasoline mixtures around the upper density range of NGLs. It also affirms that relative density is not a highly precise parameter in predicting vapor pressures of widely variable NGL compositions.

For these and other reasons, the NGL measurement industry leans toward mass calculations. Knowing fluid mixture and pure component densities allows for easy conversion from mass to component base volumes. Measured volumes are sometimes converted to mass for calculation purposes. These are called indirect or implied mass measurements.

$$m = IV * MF * \rho_f \quad \text{(Equation 5)}$$

where:

- m = Mass (Implied)
- IV = Meter's Indicated Volume
- MF = Meter Factor
- ρ_f = Density at flowing conditions

Other times NGL is measured by mass. Sometimes weight is used when mass is required. They are not the same. Confusion is added by the common use of vocabulary, such as “pounds” or “kilograms,” to describe both mass and weight.

Mass is an extensive property of matter; a measurement of the amount of a substance. Weight is a measurement of force ($force = mass \times acceleration$), the force that results from the action of gravity on the substance. Objects with the same mass (same number and kind of molecules) can have different weights, depending on where they are weighed. Different locations on the surface of the earth may have different gravitational forces.

There are many factors which affect the acceleration due to gravity at a particular point on the earth's surface such as:

- Geology - the density of material beneath the location,
- Latitude - because the earth is an oblong spheroid (the diameter of the earth at the equator is greater than the diameter at the poles),
- Altitude - measurements farther away from the center of the earth tend to have less acceleration due to gravity,
- And other gravitational forces from the sun, moon, and local topography (Bouguer anomaly).

Therefore, it is best to use a measured value for the local acceleration due to gravity to convert weight to mass or use measurement devices calibrated to mass. Otherwise, formulas or geodesic data may be available for estimating the local acceleration due to gravity.

To find the mass of an object from its weight, a standard gravity (980.665 cm/s^2 or approximately 32.1740 ft/s^2) is related to the local gravity where the mass was weighed. The equation to convert weight to mass is:

$$m = W \times g_0 \div g \quad \text{(Equation 6)}$$

where:

- m = Mass
- W = Weight
- g_0 = gravitational constant (980.665 cm/s^2 or approximately $32.1740 \text{ lb}_m\text{-ft/lb}_f\text{-s}^2$)
- g = local acceleration due to gravity

For example, in Anchorage, Alaska, the acceleration due to gravity is about $32.24 \text{ lb}_m\text{-ft/lb}_f\text{-s}^2$. If the net weight of a transaction is 1,350,495 lbs:

$$m = 1,350,495 \times 32.1740 \div 32.24$$
$$m = 1,347,720$$

MASS TO VOLUME CONVERSIONS

Although generally more accurate to measure by mass, custody of NGLs are often transferred by volume. Given a representative analysis, mass can be converted to component volumes. This is done by multiplying the total mass by the mass fraction of each component, giving the mass of each component. Dividing each component's mass by the absolute density of the component yields the component's volume. The absolute density of the components can be found in GPA 2145. However, contracts may require the use of other standards or variations to GPA 2145. The procedures for converting mass natural gas liquids to equivalent liquid volumes are found in GPA 8173 (API MPMS 14.4).

NGL analyses may be presented in mole percent or volume percent, according to the calibration of the analytical instrument. To calculate component volumes from total mass, these analyses must first be converted to mass percent. Mole percent is converted to mass percent (see Table 1) by:

- 1) Dividing each mole percent by 100 to convert to mole fraction
- 2) Multiplying mole fractions by the component's molar mass to get mass portion
- 3) Dividing component mass portion by total mass portion to get mass fractions

Component	Mole Percent	Constant	Mole Fraction	Molar Mass ¹	Mass Portion of Mixture	Mass Fraction
Carbon Dioxide	0.08	÷ 100	= 0.0008	× 44.0095	= 0.035208	0.0008 ³
Methane	2.65	÷ 100	= 0.0265	× 16.0425	= 0.425126	0.0098
Ethane	38.10	÷ 100	= 0.3810	× 30.0690	= 11.456289	0.2628
Propane	35.77	÷ 100	= 0.3577	× 44.0956	= 15.772996	0.3617 ⁴
Normal Butane	9.56	÷ 100	= 0.0956	× 58.1222	= 5.556482	0.1275
Iso Butane	4.78	÷ 100	= 0.0478	× 58.1222	= 2.778241	0.0637
Normal Pentane	1.91	÷ 100	= 0.0191	× 72.1488	= 1.378042	0.0316
Iso Pentane	0.94	÷ 100	= 0.0094	× 72.1488	= 0.678199	0.0156
Hexanes+	6.21	÷ 100	= 0.0621	× 88.7716 ²	= 5.512716	0.1265
Totals	100		1.0000		43.593299	1.0000

Table 1 – Converting Mole Percent to Mass Fraction

Table 1 notes:

¹ Values for molar mass are from GPA 2145-09

² The “Hexanes+” molar mass value is a characterization from an extended analysis or GPA 2103 tests

³ Component Mass Fraction of Mixture = Component Mass per Mole of Mixture ÷ Total Mass per Mole of Mixture

$$w_i = M_i \div M_{total} \quad (\text{Equation 7})$$

where:

- = Component Mass Fraction of Mixture; formerly Weight Fraction
- = Component Mass per Mole of Mixture
- = Total Mass per Mole of Mixture

For example:

- Using Equation 7, CO₂ Component Mass Fraction of Mixture = CO₂ Component Mass Per Mole of Mixture ÷ Total Mass per Mole of Mixture
- 0.0008 = 0.035208 ÷ 43.593299

⁴ The mass fraction of propane was adjusted to normalize the total mass fraction to unity

In a similar manner, component volume percentages can be converted to component mass fractions (see Table 2) by:

- 1) Dividing each volume percent by 100 to convert to volume fraction
- 2) Multiplying volume fractions by the component’s absolute density to get mass portion
- 3) Dividing component mass portion by total mass portion to get mass fractions

Component	Volume Percent	Constant	Volume Fraction	Absolute Density ¹	Mass					
					Portion of Mixture	Mass Fraction ³				
Carbon Dioxide	0.05	÷	100	=	0.0005	×	6.8129	=	0.003406	0.0008 ⁴
Methane	1.56	÷	100	=	0.0156	×	2.5000	=	0.039000	0.0097
Ethane	35.40	÷	100	=	0.3540	×	2.9704	=	1.051522	0.2622
Propane	34.23	÷	100	=	0.3423	×	4.2285	=	1.447416	0.3611 ⁵
Normal Butane	10.87	÷	100	=	0.1087	×	4.8706	=	0.529434	0.1320
Iso Butane	5.23	÷	100	=	0.0523	×	4.6925	=	0.245418	0.0612
Normal Pentane	2.43	÷	100	=	0.0243	×	5.2584	=	0.127779	0.0319
Iso Pentane	1.18	÷	100	=	0.0118	×	5.2120	=	0.061502	0.0153
Hexanes+	9.05	÷	100	=	0.0905	×	5.5733 ²	=	0.504384	0.1258
Totals	100				1.0000				4.009861	1.0000

Table 2-Converting Volume Percent to Mass Fraction

Table 2 notes:

¹ Values for absolute density are from GPA 2145-09

² The “Hexanes+” absolute density is a characterization from an extended analysis or GPA 2103 tests

³ Mass fractions vary between mole analysis and volume analysis due to rounding

⁴ Component Mass Fraction of Mixture = Component Mass per Mole of Mixture ÷ Total Mass per Mole of Mixture (see Equation 7)

For example:

- Using Equation 7, CO2 Component Mass Fraction of Mixture = CO2 Component Mass Per Mole of Mixture ÷ Total Mass per Mole of Mixture
- 0.0008 = 0.003406 ÷ 4.009861

⁵ The mass fraction of propane was adjusted to normalize the total mass fraction to unity

From the mass fractions, the component volumes can be calculated (see Table 3). This is done by:

- 1) Multiplying each of the component mass fractions by the total mass measurement to get the mass of each component
- 2) Dividing each component’s mass by the component’s absolute density to get the component’s volume at base conditions

Component	Mass Fraction	Total Measured Mass	Component Mass	Absolute Density	Component Volume (US gallons @EVP, 60°F)				
Carbon Dioxide	0.0008	×	1,347,720	=	1,078.176	÷	6.8129	=	158
Methane	0.0098	×	1,347,720	=	13,207.656	÷	2.5000	=	5,283
Ethane	0.2628	×	1,347,720	=	354,180.816	÷	2.9704	=	119,237
Propane	0.3617	×	1,347,720	=	487,470.324	÷	4.2285	=	115,282
Normal Butane	0.1275	×	1,347,720	=	171,834.300	÷	4.8706	=	35,280
Iso Butane	0.0637	×	1,347,720	=	85,849.764	÷	4.6925	=	18,295
Normal Pentane	0.0316	×	1,347,720	=	42,587.952	÷	5.2584	=	8,099
Iso Pentane	0.0156	×	1,347,720	=	21,024.432	÷	5.2120	=	4,034
Hexanes+	0.1265	×	1,347,720	=	170,486.580	÷	5.5733	=	30,590
Totals	1.0000				1,347,720.000				336,258

Table 3 – Converting Mass Fraction and Mass to Component Volumes

The resulting component volumes can then be used for transaction evaluation and plant allocation. Other calculations may be necessary for operations, balancing, and reporting.

PHASE VOLUME CONVERSIONS

Phase volume conversions, converting liquids to gas equivalents and gas to liquid equivalents, are common operational calculations in the NGL industry. These conversions aid in accounting, material balancing and understanding plant efficiency.

Phase volume conversion calculations are accomplished with Theoretical Hydrocarbon Liquid Content (*THLC*) values. A gas component's *THLC* is the product of its mole fraction and the inverse of its ft³ ideal gas per gallon liquid factor, divided by the compressibility of the gas, converted to the contract pressure base. In the United States, this factor is generally reported per 1,000 cubic feet of gas. In equation form:

$$THLC = \frac{x_i}{z} \times \frac{V_l}{V_g} \times \frac{P_b}{P_s} \times 1000 \quad (\text{Equation 8})$$

where:

- THLC* = Theoretical Hydrocarbon Liquid Content
- x_i = mole fraction of component
- z = compressibility of gas mixture
- V_l/V_g = component gallon liquid/ft³ ideal gas factor derived from the reciprocal of ft³ ideal gas/gallon liquid value from GPA 2145-09
- P_b = contract pressure base
- P_s = reference pressure base

This calculation can be found in GPA 2172-09 (API *MPMS* 14.5). As an example, given a gas mixture with 0.0440 mole fraction propane (x_i), compressibility of the gas (z) as 0.99673, and a contract pressure base (P_b) of 14.65 absolute psi, using Equation 8:

$$THLC = \frac{.0440}{0.99673} \times \frac{1}{36.391} \times \frac{14.65}{14.696} \times 1000 = 1.209$$

In this example, a thousand cubic feet of gas potentially yields 1.209 gallons of propane. The *THLC* is multiplied by the total volume of the mixture for the operational period, resulting in the theoretical liquid volume for the propane. This process is repeated for each of the components in the gas mixture, as required by the application. Often, only the values for hydrocarbon components with two or more carbon atoms (Ethane+) are converted to a total *THLC* because these are the main components processed as NGLs.

Gas stream component *THLCs* provide a basis for transaction evaluation. Knowing the potential liquids to be generated from a particular gas stream helps to place a value on each of the gas streams entering a gas processing plant. The difference between the actual liquids generated by the plant and the potential liquids entering the plant over an operational period is a good indicator of the plant's efficiency.

Invariably, some of the NGL components from the gas stream(s) exit the plant's demethanizer as residue gas. For this reason, it is more efficient to convert a plant's NGL product to gas for balancing purposes. The NGL converted to a gas equivalent volume, combined with the residue gas, can be compared with the total inlet gas for a specific operational period. A gas equivalent factor can be found from the above *THLC* calculation process by taking the reciprocal of the total *THLC*. Inlet gas can be compared to the sum of the gas equivalent liquid product volumes and plant residue gas to balance the plant. This type

of balance provides not only a reflection of the plant's efficiency, but also helps identify quantity and quality measurement errors.

These phase volume conversion calculations involve combining individual component values to get full station stream values. This provides high level information about quantity measurements. But again, these quantity calculations leave out the consideration for shrinkage due to molecular mixing. Therefore, NGL balances are also commonly performed at the component level.

Component level balancing provides additional information about quality analysis and plant efficiency. At the same time, the results better correspond to the level at which transactions take place.

CONCLUSION

Different operations and stakeholders will require different information. Some will need more detailed information than others. Some applications will lend themselves to volumetric measurement, where others are better suited to mass. These calculations associated with NGLs help to take those different types of measurements, calculate the various results stakeholders require, and provide the basis for NGL evaluations and transactions.