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 for proper accounting.

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 NGLs 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 NGLs. Measurements can be made on a mass basis or a volumetric basis.

MEASUREMENT BY VOLUME

When NGLs are measured volumetrically, the measured volume is converted to contract base conditions. Conditions consist of a specified absolute pressure and temperature. Contract base conditions are pressure and temperature conditions specified in the contract between the buyer and seller. The American Petroleum Institute (API) Manual of Petroleum Measurement Standards (MPMS), Chapter 12, 1996 Edition [1], a.k.a. API-12, provides guidance for this calculation process. Because NGLs are processed hydrocarbon liquids, they have no sediment or water in them. Therefore, the Gross Standard Volume (GSV) is equal to the Net Standard Volume (NSV). GSV is the volume indicated by the meter, corrected for the performance of the meter and the conditions of the liquid. The corrections to the indicated volume output by the meter are grouped together into a Combined Correction Factor (CCF).

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

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:

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

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

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1. Manual of Petroleum Measurement Standards, Chapter 12, “Calculation of Petroleum Quantities,” 1996 Edition, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

CCF is the product of two correction factors: the correction for the performance of the meter (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.

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

where:

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

According to API-12, Section 2, Part 2, the meter factor (MF) is "used to adjust the indicated volume ($MR_C - MR_O$) of a meter for inaccuracies associated with the meter's performance as determined at the time of proving." [2] It is "a number obtained by dividing the volume of the liquid passed through the prover corrected to standard conditions during proving by the indicated standard volume (ISV_m) as registered by the meter." [3]

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.

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

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 (a.k.a. API-11), Section 2, Part 4.[4] It is a function of the density and temperature of the liquid. It corrects the volume of the liquid from one temperature to another; i.e., 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 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 a change in product temperature, especially with lighter NGLs, may be several percent. With large volumes or long periods of time, the difference in the value of the product 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 pressure, temperature, and density of the liquid. 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-11 Section 2 Part 2.[5] 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 Section 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 will be handled.

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2. API Manual of Petroleum Measurement Standards, Chapter 12, Section 2, Part 2, Page 5, Paragraph 2.9.2.
3. API Manual of Petroleum Measurement Standards, Chapter 12, Section 2, Part 2, Page 3, Paragraph 2.8.1.8.
4. Manual of Petroleum Measurement Standards, Chapter 11, "Physical Properties Data (Volume Correction Factors)," Section 2, Part 4, "Temperature Correction for the Volume of NGL and LPG Tables 23E, 24E, 53E, 54E, 59E, and 60E," 2007 (1st) Edition, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.
5. Manual of Petroleum Measurement Standards, Chapter 11, "Physical Properties Data (Volume Correction Factors)," Section 2, Part 2, "Compressibility Factors for Hydrocarbons: 0.350-0.637 Relative Density (60°F/60°F) and -50°F to 140°F Metering Temperature," 2012 Edition, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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 saturation pressure of the liquid. Saturation pressure is the pressure 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*, and *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 NSVs can be calculated from the same input data.

In addition to the rounding guidelines in API-11, API-12 (1996 Edition) provides guidance on rounding, as well as the discrimination levels of input, intermediate, and final values, all of 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), which is a function of the composition of the liquid or the observed density, temperature, and pressure of the liquid
2. Determine the Correction for the Temperature and Pressure of the Liquid (C_{TPL}), which is a function of the temperature, pressure, equilibrium vapor pressure, and base density of the liquid
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 Section 2, Part 4 (also, GPA TP-27[6]), 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 are not a very broad range of reference data to formulate calculations for the wide array of combinations of hydrocarbons that 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 the saturation pressure of a fluid is presented in API-11 Section 2, Part 5[7]. As with C_{TL}, this standard is based on the density of the liquid, 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 the 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.

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

where:
m = Mass (Implied)

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[6] GPA TP-27, "Temperature Correction for the Volume of NGL and LPG Tables 23E, 24E, 53E, 54E, 59E & 60E," 2007 Edition, GPA Midstream Association, Sixty Sixty American Plaza, Suite 700, Tulsa, OK 74135.

[7] Manual of Petroleum Measurement Standards, Chapter 11, "Physical Properties Data (Volume Correction Factors)," Section 2, Part 5, "A Simplified Vapor Pressure Correlation for Commercial NGLs," 2012 Edition, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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* × *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 can have different gravitational forces.

There are many factors that affect the acceleration due to gravity at a 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:

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

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

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

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

Although it is technically correct to adjust the weight for the acceleration due to gravity, this is often ignored because the correction is usually less than the tolerance of the scale.

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 mass of each component by the absolute density of the component yields the volume of the component. The absolute density of the components can be found in GPA 2145[8]. However, contracts

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[8] GPA 2145, "Table of Physical Properties for Hydrocarbons and Other Compounds of Interest to the Natural Gas Industry," 2016 Edition, GPA Midstream Association, Sixty Sixty American Plaza, Suite 700, Tulsa, OK 74135.

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[9] (also, API-14 Section 4[10]).

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 factions 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
Isobutane	4.78	÷	100	=	0.0478	×	58.1222	=	2.778241	0.0637
Normal Pentane	1.91	÷	100	=	0.0191	×	72.1488	=	1.378042	0.0316
Isopentane	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 2145-16

[2] The "Hexanes+" molar mass value is a characterization from an extended analysis or GPA 2103[11] tests

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

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

where:

w_i = Component Mass Fraction of Mixture; formerly Weight Fraction
M_i = Component Mass per Mole of Mixture
M_{total} = Total Mass per Mole of Mixture

For example:

- Using Equation 7, CO_2 Component Mass Fraction of Mixture = CO_2 Component Mass Per Mole of Mixture ÷ Total Mass per Mole of Mixture
- 0.0008 = 0.035208 ÷ 43.593299

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9. GPA 8173, "Method for Converting Mass of Natural Gas Liquids and Vapors to Equivalent Liquid Volumes," 1994 Edition, GPA Midstream Association, Sixty Sixty American Plaza, Suite 700, Tulsa, OK 74135.
10. Manual of Petroleum Measurement Standards, Chapter 14, "Natural Gas Fluids Measurement," Section 4, "Converting Mass of Natural Gas Liquids and Vapors to Equivalent Liquid Volumes," 1st Edition, 2006, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.
11. GPA 2103, "Tentative Method for the Analysis of Natural Gas Condensate Mixtures Containing Nitrogen and Carbon Dioxide by Gas Chromatography," 2003 Edition, GPA Midstream Association, Sixty Sixty American Plaza, Suite 700, Tulsa, OK 74135.

[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 absolute density of each component 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
Isobutane	5.23	÷	100	=	0.0523	×	4.6925	=	0.245418	0.0612
Normal Pentane	2.43	÷	100	=	0.0243	×	5.2584	=	0.127779	0.0319
Isopentane	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 2145-16

[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, CO_2 Component Mass Fraction of Mixture = CO_2 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 the mass of each component by the absolute density of each component to get the volume of each component at base conditions

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

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
Isobutane	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
Isopentane	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

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. The $THLC$ of a gas component is the product of its mole fraction and the inverse of its ft^3 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:

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

where:

$THLC$ = Theoretical Hydrocarbon Liquid Content
x_i = mole fraction of component
z = compressibility of gas mixture
${V_l}\big/{V_g}$ = component gallon liquid/ft^3 ideal gas factor derived from the reciprocal of ft^3 ideal gas/gallon liquid value from GPA 2145-16
P_b = contract pressure base
P_s = reference pressure base

This calculation can be found in GPA 2172-09[12] (API-14 Section 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:

$$THLC = \frac{.0440}{0.99673} \times \frac{1}{36.391} \times \frac{14.65}{14.696} \times 1000 = 1.209 \qquad \text{(Equation 9)}$$

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.

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12. GPA 2172, "Calculation of Gross Heating Value, Relative Density, Compressibility and Theoretical Hydrocarbon Liquid Content for Natural Gas Mixtures for Custody Transfer," 2009 Edition, GPA Midstream Association, Sixty Sixty American Plaza, Suite 700, Tulsa, OK 74135.

Gas stream component $THLC$s 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 efficiency.

Invariably, some of the NGL components from the gas stream(s) exit the de-methanizer at the plant as residue gas. For this reason, it is more efficient to convert the NGL product at a plant 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 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.