MASS MEASUREMENT OF NATURAL GAS LIQUID MIXTURES
Class 2250

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Introduction

The purpose of this paper is to review methods for directly or indirectly determining the mass of Natural Gas Liquid (NGL) streams. NGL's by definition are hydrocarbons liquefied by gas processing plants containing ethane, propane, butane, and natural gasoline.

Mass and Weight

People tend to confuse the terms mass and weight and use them interchangeably. However, they are not the same. Mass is defined as the amount of matter ("stuff") in a particle or object. Since the amount of matter in an object or particle cannot change without a change in structure of the object or particle, it is absolute. Weight is defined as "The force exerted on an object's mass compared with a reference standard."[1] By equation:

$$weight = mass * g / gc$$

$$\text{where } g = \text{acceleration of gravity}$$

$$gc = \text{conversion constant} = 32.174 \frac{lb_m - ft}{lb_f - sec^2}$$

Figure 1 - Calculating Weight from Mass

For the earth, the typically used value for g is 32.174. However the value varies from location to location. The value for Chicago, Illinois is 32.161. On the moon the value is roughly $1/6^{th}$ of that on the earth, or 5.25. A person having a mass of 180 pounds would weight 179.9 pounds in Chicago, and 29.3 pounds on the moon, but the person would still have a mass of 180 pounds in either location.

Solution Mixing

Solution mixing occurs when compounds containing different sized molecules are mixed together. The smaller molecules will tend to fit into the voids created by the structure of the larger molecules. A simple example of this effect can be described using sand and rocks. Assume a person is building a sand and gravel base for a patio. In calculating the volume of gravel and sand required to product a 4" high base, consisting of 2" of each product, they person determines that the total volume is 1 yard, or 27 cubic feet. The person proceeds to order equal amounts of sand and gravel, 13.5 cubic feet of each. When base is built up using the sand and gravel, there is astonishment when the built up base is much less that 4" high. In fact a good portion of the sand has settled between the gravel. Similarly, when hydrocarbons of varying sizes are mixed together, volumetrically there will always be some solution mixing effect resulting from smaller molecules mixing in between larger molecules. Figure 2 shows the relative molecular structure and size of Normal Butane, Propane, and Ethane respectively.

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[1] API MPMS Chapter 1

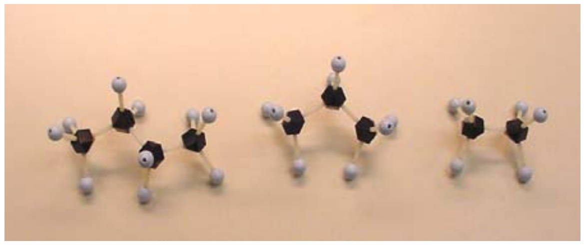

Figure 2 - Molecular Models of N-Butane, Propane, and Ethane Respectively

Volumetric tables could be created to take the shrinkage into account, but because NGL's are comprised of everything from Methane to Decanes and larger, it would be an impossible task to properly account for the solution mixing in every possible NGL mixture. Because of this mass measurement is the preferred means of measuring NGL's.

<u>Direct and Indirect Measurement Devices</u>

There are two ways one can measure product, direct and indirect. Direct measurement involves the unit of measure being directly measured by the device. For example, in the case of volumetric measurement, a PD meter directly measures volume. The chambers in the meter are directly proportional to the volumetric flow. Similarly, length is a direct measurement in that the user directly reads the length of an object from a ruler, tape measure, or other similar device. On the other hand, a turbine meter is an indirect volumetric meter in that the turbine rotates proportional to the velocity of the fluid. Likewise, area is an indirect measurement in that if one is measuring the area of a wall, the length and height must be determined and multiplied together to produce the area of the wall. In mass measurement, a truck scale is considered a direct measurement device. A Coriolis meter can be considered either direct or indirect. Purists point to the fact that a Coriolis meter is actually based on the relationship between mass and acceleration, Force=Mass*Acceleration. Others point to the fact that the primary output of a Coriolis meter is a mass pulse, so it is a direct measurement device. Indirect measurement devices include turbine meters, PD meters, and Ultrasonic meters, just to name a few. All of these devices measure either volume or velocity and must be coupled with a flowing density in order to determine mass.

<u>Density Measurement</u>

Density measurement is important to devices that either measure volume or are referential volume devices. In this case, volume is measured or inferred by the device at flowing temperature, and pressure. In order to determine the mass, the density at the same flowing conditions must be determined. For dynamic measurement, this is generally accomplished using a densitometer.

<u>Sampling</u>

Since NGL's are priced volumetrically, conversion from mass to volume is an important step in the process and requires determining the composition of the product. To determine the composition as accurately as possible, the composition should be measured proportional to flow and flow weighted over the duration of the product movement

<u>Determination of Mass</u>

For direct measurement devices, mass is determined by simply reading the output of the mass measurement device and requires no additional calculation.

For indirect measurement device, specifically devices that produce a volumetric result either directly or indirectly, mass is determined by the following basic equation:

$$Mass = IndicatedVolume * Meterfactor * Density$$

where $InidcatedVolume$ is the volume measured at flowing conditions before applying any meter correction factors and the density is the density of the NGL stream at flowing conditions.

Figure 3 - Calculating Mass Indirectly

Take the following example: A turbine meter measures 30,000 barrels of product at flowing conditions with a meter factor of 0.9917 and a flowing density of 0.4876 grams per cc, the mass is calculated as follows:

$$\text{Mass} = (30000 * 0.9917) * (0.4867 * 8.345406) * 42$$

$$\text{Mass} = 5{,}075{,}276 \text{ pounds}$$

Where 8.345406 is the conversion from g/cc to lb/gal

and 42 represents the amount of gallons in 1 barrel.

Figure 4 - Mass Calculation Example

It is important to note that when calculating mass, all measurements must be in the same units. In other words, if the volume is in gallons, then the density must be converted to pounds per gallon. In this example by multiplying the density by 8.345406 and subsequently by 42, the density is converted to pounds per barrel.

Conversion of Mass to Volume

Converting from mass to volume involves obtaining a representative sample of the product, multiplying the weight percent of each individual component by the total mass flowed to obtain the mass of each component. The individual component mass is then converted to volume by dividing the component mass by the pure density of the component as defined in GPA 2145 or other standard as dictated by contract.

Gross	10000 Barrels	Notes: 1) From GPA 2145
Meter Factor	0.9907	
Flowing Density	0.48780 g/cc	
Mass*	1693873 Lbs	

* Mass = Gross bbls* Meter Factor*Density (lb/bbl)
Density (lb/bbl)=Density (g/cc)/0.1198264 (g/cc)/(lb/gal)*42 (gal/bbl)

Component	(A) Lbs/Gallon (1)	(B) Weight Fraction	(C) Mass	(D) Component Mass B * C	(E) Barrels @ 60F and EVP E / A
N2	6.727	0.00000	1693873	0	0
CO2	6.8534	0.00054	1693873	906	3
C1	2.5	0.00384	1693873	6503	62
C2	2.9716	0.35662	1693873	604076	4840
C3	4.2301	0.30772	1693873	521241	2934
IC4	4.6934	0.05778	1693873	97871	496
NC4	4.8696	0.13739	1693873	232717	1138
IC5	5.2074	0.03890	1693873	65888	301
NC5	5.2618	0.03684	1693873	62401	282
C6+	5.5363	0.06038	1693873	102268	440
		1.00000		1693873	10497

Figure 5 - Calculating Net Volume from Mass

The hexanes plus density is generally determined by performing an extended analysis of the sample to thoroughly characterize the hexanes plus portion of the stream.

Common Pitfalls Encountered In Mass Measurement

Proper determination of the various parameters used for mass measurement is crucial to minimizing errors. First and foremost is the proper determination of the composition during the product movement. Figure 6 shows a simple mass calculation. In Figure 7, the same mass is used, but The Ethane is reduced by 0.1% and the Propane increased by 0.1%. The result is a 3-barrel difference, or 0.02% between the two calculations.

Similarly, the characterization of the hexanes plus portion of the stream is also critical in determining the proper volume. In Figure 8, the hexanes plus density has been changed from 5.5363 in Figure 6 to 5.8414 or increased by 5.5%. The calculation yields 10,462 barrels, which is 35 barrels or 0.30% less than the calculation in Figure 6. Incidentally, the hexanes plus density in Figure 8 was from an actual extended analysis while the 5.5365 value is density of Normal Hexane.

Gross	10000	Barrels
Meter Factor	0.9907	
Flowing Density	0.48780	g/cc
Mass*	1693873	Lbs

Component	(A) LV%	(B) Lbs/Gallon (1)	(G) Barrels @ 60F and EVP F / B
N2	0.00%	6.727	0
CO2	0.03%	6.8534	3
C1	0.59%	2.5	62
C2	46.11%	2.9716	4840
C3	27.95%	4.2301	2934
IC4	4.73%	4.6934	496
NC4	10.84%	4.8696	1138
IC5	2.87%	5.2074	301
NC5	2.69%	5.2618	282
C6+	4.19%	5.5363	440
	100.00%		10497

Figure 6 - Basic Calculation

Gross	10000	Barrels
Meter Factor	0.9907	
Flowing Density	0.48780	g/cc
Mass*	1693873	Lbs

Component	(A) LV%	(B) Lbs/Gallon (1)	(G) Barrels @ 60F and EVP F / B
N2	0.00%	6.727	0
CO2	0.03%	6.8534	3
C1	0.59%	2.5	62
C2	46.21%	2.9716	4852
C3	27.85%	4.2301	2924
IC4	4.73%	4.6934	497
NC4	10.84%	4.8696	1138
IC5	2.87%	5.2074	301
NC5	2.69%	5.2618	282
C6+	4.19%	5.5363	440
	100.00%		10500

Figure 7 - Ethane and Propane Adjusted

Gross	10000	Barrels
Meter Factor	0.9907	
Flowing Density	0.48780	g/cc
Mass*	1693873	Lbs

Component	(A) LV%	(B) Lbs/Gallon (1)	(G) Barrels @ 60F and EVP F / B
N2	0.00%	6.727	0
CO2	0.03%	6.8534	3
C1	0.59%	2.5	62
C2	46.11%	2.9716	4824
C3	27.95%	4.2301	2924
IC4	4.73%	4.6934	495
NC4	10.84%	4.8696	1134
IC5	2.87%	5.2074	300
NC5	2.69%	5.2618	281
C6+	4.19%	5.8418	438
	100.00%		10462

Figure 8 - Changed C6+ Gravity

Another error is to use the density/specific gravity of the analysis as the flowing density in the calculation of mass. Figure 9 provides a plot of flowing density versus temperature at four different pressures for Propane. As is evident, the density of propane changes with pressure and more so with temperature. Likewise, NGL's have the same but more pronounced influence. This is further highlighted in Figure 10, which uses the gravity from the analysis to calculate the mass. The result is a volume 9,943 barrels that is 554 barrels or 5.28% less than the volume calculated in Figure 6.

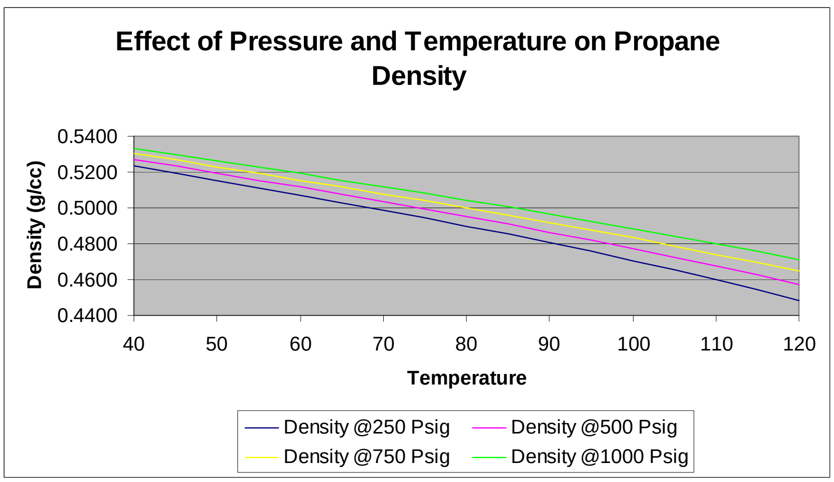

Figure 9 - Effect of Temperature and Pressure on Density

Gross	10000	Barrels
Meter Factor	0.9907	
Flowing Density	0.46205	g/cc
Mass*	1604456	Lbs

Component	(A) LV%	(B) Lbs/Gallon (1)	(G) Barrels @ 60F and EVP F / B
N2	0.00%	6.727	0
CO2	0.03%	6.8534	3
C1	0.59%	2.5	59
C2	46.11%	2.9716	4585
C3	27.95%	4.2301	2779
IC4	4.73%	4.6934	470
NC4	10.84%	4.8696	1078
IC5	2.87%	5.2074	285
NC5	2.69%	5.2618	267
C6+	4.19%	5.5363	417
	100.00%		9943

Figure 10 - Using Standard Density in Place of Flowing Density

Lastly, the other common error that is made when performing mass calculations is the use of the wrong standard densities. In many cases this error is small, but should be investigate when verifying the integrity of a mass calculation.

Conclusion

In conclusion, due to the nature of NGL's and their propensity to experience solution-mixing effects, it is desirable to determine the volume of product using mass measurement techniques. There are many ways to determine the mass of product both directly and indirectly.