Analyzing Natural Gas Composition

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Introduction

The purpose of this course is to educate one on the use of gas composition data to determine properties of hydrocarbon gases that are useful in calculations under static and dynamic conditions. Due to the peculiar interactions of hydrocarbon molecules, an analysis of the gas is needed to determine the specific gravity, critical pressure, critical temperature, heating value, and natural gas liquid content of the gas. Knowing these properties is necessary to determine the deviation from the Ideal Gas Law, flow characteristics of the gas, potential processing requirements of the natural gas, and revenue derived from sale of natural gas and natural gas liquids. Understanding how to calculate and use these natural gas properties is crucial to reservoir, production, and natural gas process engineering.

The contents of this course are as follows:

- Ideal Gas Law
- What is natural gas
- Components of natural gas
- Properties of natural gas components
- Calculation of natural gas properties from gas composition
- Conclusions

The Ideal Gas Law

In order to understand gas properties, one must understand how gases behave. Gas molecules, unlike the other phases of matter – liquids and solids, are not bound together by intermolecular and viscous forces. As such, gases completely fill whatever container in which they reside. This property is very important and can be used to determine how gases behave under the effects of pressure, temperature, and volume.

The Ideal Gas Law is an equation of state that relates pressure, temperature, and volume. This equation is the result of combining Boyle's law, Charles' law, Avogadro's law, and Gay-Lussac's law. Shown below is the Ideal Gas Law equation of state:

$$PV = nRT$$

where,

P = pressure (psia – pounds per square inch absolute)
V = volume (scf – standard cubic feet)
T = temperature (^oR - degrees Rankine)
n = number of moles of gas (moles)
R = ideal gas constant (10.73 scf-psia/mole-^oR)

The purpose of R, the ideal gas constant is to convert to consistent units. Depending on the units used, R will change. It should always be remembered that when dealing with gases, temperature is always in absolute units (i.e., Kelvin or Rankine). In the USA, we use units of Rankine (Fahrenheit plus 459.67 degrees).

Based on the Ideal Gas Law, one can derive a very important relationship. If a gas is composed of different types of molecules (i.e., nitrogen, oxygen, etc.), the volume percentage of each gas is equal to the molar percentage of that gas. This can be shown as follows:

Let *V* be the total gas volume and N be the total number of moles. The Ideal Gas Law equation is then:

$$PV = NRT$$

Let *v* be the volume of a single gas component and n be the moles of that component. The Ideal Gas Law for that component is then:

$$Pv = nRT$$

Taking a ratio of the individual gas component to the total gas gives the following:

$$\frac{Pv}{PV} = \frac{nRT}{NRT}$$

Since P, R, and T are all equal, this equation can be simplified as:

$$\frac{v}{V} = \frac{n}{N}$$

This clearly shows that the ratio of an individual component to the total volume is the same as the number of moles of a component to the total number of moles of gas. This is very important because gas samples are analyzed in the laboratory and the results presented as mole percentages, which in effect are volume percentages.

This equation of state works well under normal ranges of pressure and temperature when the interaction between molecules is relatively small. In the case of hydrocarbon gases, however, the molecular interactions are not small and must be taken into account. For that purpose, the Ideal Gas Law is modified to account for these interactions. Shown below is the Ideal Gas Law equation modified for hydrocarbon gases:

$$PV = nRTz$$

where,

z = gas deviation factor

This course will not discuss how to calculate z, or look it up in a table or find it on a graph. The value for z, however, does depend on the constituents that make up the natural gas. Specifically, the value of z depends on the gas specific gravity and the reduced pressure and reduced temperature. The reduced pressure is the measured pressure divided by the critical pressure and the reduced temperature is the measured temperature divided by the critical temperature. The determination of the critical pressure and temperature will be discussed in a later section of this course. However, shown below are the equations for the reduced pressure and temperature.

$$Pr = P/Pc$$

$$Tr = T/Tc$$

where,

Pr = reduced pressure
P = measured pressure (psia)
Pc = critical pressure (psia)
Tr = reduced temperature
T = measured temperature (^{o}R)
Tc = critical temperature (^{o}R)

Example Problem:

How many moles of gas are there in the container given the following data:

Container volume = 2 scf
Temperature = 80 ^oF
Pressure = 500 psia

Answer:

The first thing to do is calculate the temperatures in absolute temperature degrees, so the temperature is:

T = 80 + 459.67 = 539.67 ^oR

Rearrange the Ideal Gas Law equation to solve for "*n*" as shown below:

$$n = \frac{PV}{RT} = \frac{(500) * (2)}{(10.73) * (539.67)} = 0.17\ moles$$

What is Natural Gas

Most of us think of natural gas as something we use in our homes for heating or cooking. It is true that we tend to call gas delivered to our homes as "natural gas", but in reality, it is a nearly single component called "methane" that is derived from natural gas. So, what is natural gas and what is it composed of?

Webster's Dictionary defines natural gas as

> *"gas issuing from the earth's crust through natural openings or bored wells, especially a combustible mixture of methane and other hydrocarbons used chiefly as a fuel and raw material"*

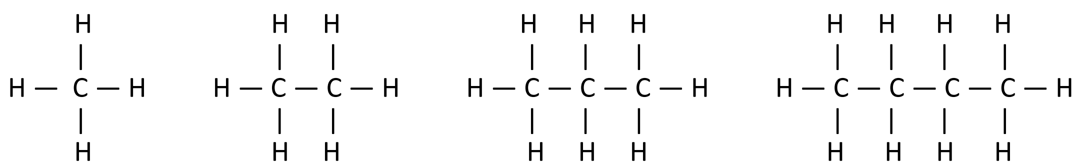
Natural gas is created in the earth's crust by the decay and reduction of organic material. As organic material is deposited on the earth's surface and subsequently buried, it is subjected to increased pressure and temperature. As this process continues, the organic material is reduced to petroleum. Depending on the composition of the original organic matter, the temperature, and pressure, the petroleum is either gaseous or liquid. As this petroleum forms, it begins to seep and being lighter than water, begins to move toward the earth's surface. This seeping petroleum moves along faults or through porous rocks and either makes it to the surface or is trapped along the way. There are various ways petroleum can be trapped, but most commonly with some type of seal like an impervious rock layer that prevents its further upward movement. The trapped petroleum exists in porous rocks known as reservoirs. Natural gas can exist in reservoirs as a gas or can be liberated from oil as it is produced. Natural gas can also exist in coal seams and is referred to as coalbed methane or coal seam gas. In the case of gas existing in coal seams, the coal is both the source rock and reservoir and the gas is actually attached to the surface of the coal.

Although there are gases emanating from the earth that do not contain hydrocarbons (i.e., nitrogen and carbon dioxide), the discussions in this course will be concerned only with hydrocarbon natural gases. Unlike non-hydrocarbon gases, hydrocarbon gases behave quite differently to pressure and temperature. With the exception of very high pressures and temperatures, non-hydrocarbon gases closely follow the Ideal Gas Law. The Ideal Gas Law is an equation of state that relates pressure, temperature and volume. Due to the interaction of hydrocarbon molecules, hydrocarbon gases deviate from the Ideal Gas Law. By analyzing the composition of natural gas, one can adjust the Ideal Gas Law to account for these interactions and properly calculate the relationship between pressure, temperature and volume.

Components of Natural Gas

The most common hydrocarbon constituents of natural gas are known as alkanes or paraffins. An alkane is a molecule composed of carbon and hydrogen with single bonds between the atoms and forming a chain-like structure. The simplest alkane is methane, which consists of a single carbon atom connected to four hydrogen atoms. Alkanes are named by the number of carbon atoms that make up the molecule. After methane, the next molecule containing two carbon atoms is called ethane. An alkane containing three carbon atoms is propane. Shown below are diagrams of the first four alkanes.

Methane Ethane Propane Butane



The first thing to notice is that there is a relationship between the number of hydrogen atoms and the number of carbon atoms. If n is the number of carbon atoms, then the number of hydrogen atoms is 2n+2. Since there is a direct relationship between the carbon and hydrogen atoms that comprise alkane molecules, there is also a direct relationship between the molecular weight and heating content of the alkanes.

The molecular weight of carbon is approximately 12 pounds per pound-mole and the molecular weight of hydrogen is approximately 1 pound per pound-mole. Using the formula for the relationship between the number of carbon and hydrogen atoms gives an increase of 14 pounds per pound-mole for each increment in alkanes.

Hydrocarbons create energy by reacting with oxygen (i.e., burning or combustion). If one combines a hydrocarbon with oxygen, the result is carbon dioxide (CO_2), water (H_2O), and heat. The amount of heat is directly proportional to the amount of carbon, hydrogen, and oxygen consumed in the process. Shown below are the equations for combustion for the first four alkanes.

Methane	$CH_4 + 2\ O_2 = CO_2 + 2\ H_2O$ + Heat
Ethane	$2\ C_2H_6 + 7\ O_2 = 4\ CO_2 + 6\ H_2O$ + Heat
Propane	$C_3H_8 + 5\ O_2 = 3\ CO_2 + 4\ H_2O$ + Heat
Butane	$2\ C_4H_{10} + 13\ O_2 = 8\ CO_2 + 10\ H_2O$ + Heat

The measurement of heat in the USA are units of British Thermal Units (Btu), which is defined as the heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit. The heating value of gas is typically defined as Btu per standard cubic foot of gas. Standard conditions for Btu measurements are a pressure of 14.65 psia and a temperature of 60^{o}F (or 520 ^{o}R). The heating value of methane is 1,010 Btu per standard cubic foot. For each added carbon of an alkane, the Btu content increases approximately 750 Btu per cubic foot.

Example Problem:

How many hydrogen atoms are in a molecule of octane (8 carbons atoms)? What is the estimated molecular weight? What is the approximate heating value of 1 standard cubic foot of octane?

Answer:

Using the equation that hydrogen atoms are 2n+2 carbon atoms:

2 x 8 + 2 = 18 hydrogen atoms in octane

The estimated molecular weight is 12 times the number of carbon atoms plus 1 times the number of hydrogen atoms as:

Estimated molecular weight of octane = 12 x 8 + 1 x 18 = 114 pound per pound-mole

As stated above, the heating value increases approximately 750 Btu for each carbon added beyond methane. For octane, the number of added carbon atoms beyond methane is 8 – 1 = 7 carbon atoms. The estimated heating value of octane would be:

Estimated octane heating value = 1,010 + 7 x 750 = 6,260 Btu per standard cubic foot

Besides the major alkane hydrocarbons, there are other constituents of natural gas that occur. The most common of these are:

Air
Nitrogen (N_2)
Oxygen (O_2)
Carbon Dioxide (CO_2)
Hydrogen Sulfide (H_2S)
Hydrogen (H_2)
Argon (Ar)
Helium (He)

When computing properties of natural gas, these constituents must be taken into account as they affect the overall properties of the gas. As a rule, most of these constituents occur in minor amounts. The exception to this rule are carbon dioxide (CO_2) and nitrogen (N_2) which can sometimes occur in large amounts. Although some gas contracts allow for small amounts of non-hydrocarbons in the gas stream, prior to sale or use for commercial purposes, the major portion of these constituents must be removed. In gases containing hydrogen sulfide (H_2S), this constituent is extremely toxic and must always be removed prior to transmission or sale.

Table 1 shown on the next page lists the most common constituents of natural gas along with their molecular formula, molecular weight, critical pressure, critical temperature, heating value, and hydrocarbon liquid content. Occasionally, a natural gas contains other gases such as benzene or toluene. If these are present, their properties can be added to the table and used to calculate overall properties of the gas. The footnote on Table 1 gives the source of the gas property data and can be referenced for additional constituents.

Table 1
Properties of Common Constituents of Natural Gases

Component	Molecular Formula	[1,2]Molecular Weight	[1,2]Critical Pressure (psia)	[1,2,3]Critical Temperature (^oR)	[1,2]Heating Value (btu/scf)	[1,2]Liquid Hydrocarbon Volume (ft^3/gal)
Methane	CH_4	16.042	667.00	343.01	1010.0	59.138
Ethane	C_2H_6	30.069	706.60	549.59	1769.7	37.503
Propane	C_3H_8	44.096	615.50	665.59	2516.2	36.404
Iso-Butane	C_4H_{10}	58.122	527.90	734.08	3252.0	30.644
N-Butane	C_4H_{10}	58.122	550.90	765.22	3262.4	31.794
Iso-Pentane	C_5H_{12}	72.149	490.40	828.67	4000.9	27.390
N-Pentane	C_5H_{12}	72.149	488.80	845.47	4008.7	27.676
Hexane	C_6H_{14}	86.175	436.90	913.47	4756.0	24.380
Heptane	C_7H_{16}	100.202	396.80	972.57	5502.5	21.729
Octane	C_8H_{18}	114.229	360.70	1,023.87	6248.9	19.582
Nonane	C_9H_{20}	128.255	330.70	1,070.47	6996.4	17.807
Decane	$C_{10}H_{22}$	142.282	304.60	1,111.87	7743.0	16.323
Air		28.959	551.90	238.70	0.0	0.000
Nitrogen	N_2	28.014	492.50	227.14	0.0	0.000
Oxygen	O_2	31.999	731.40	278.24	0.0	0.000
Carbon Dioxide	CO_2	44.010	1,070.00	547.45	0.0	0.000
Hydrogen Sulfide	H_2S	34.082	1,306.50	672.48	637.1	0.000
Hydrogen	H_2	2.016	190.70	59.77	324.2	0.000
Argon	Ar	39.948	705.32	271.24	0.0	0.000
Helium	He	4.003	33.00	9.35	0.0	0.000

Notes:

1 - From Gas Processors Suppliers Association Engineering Data Book, Twelfth Edition, 2004
2 - From NIST Chemistry WebBook, SRD 69 https://webbook.nist.gov/chemistry/fluid/
3 - Degrees Rankine = Degrees Fahrenheit + 459.67

Calculation of Natural Gas Properties from Gas Composition

The composition of a natural gas is made by analyzing a sample of the gas. The sample can be taken directly form the reservoir using a special device or can be taken at the surface from the production facilities. Once the sample is taken it is sent to a laboratory where measurements of the components and their proportion of the total gas are made.

The amount of each component of the gas sample is reported as "Mole %" which is the percentage of the number of molecules of the component divided by the total number of gas molecules. For a gas, the Mole % is the same as the volume percent.

Shown below in Table 2 is an example of a gas sample.

Table 2
Example Gas Sample

Component	Measured Mole %
Methane	79.28
Ethane	3.55
Propane	3.43
I-C4	1.80
N-C4	1.54
I-C5	1.66
N-C5	1.30
C6	1.92
C7	0.88
C8	0.75
C9	0.00
C10	0.00
O2	0.00
N2	2.44
CO2	1.30
H2S	0.00
Ar	0.15
Total	100.00

Notice that many of the components are simply listed as the number of carbon atoms in the molecule. This is common practice in some labs. It is fortunate that this gas sample that the total of the constituents add up to 100 percent. In some cases, the total is not 100% and must be adjusted so the total is equal to 100 percent. Due to the methods used and the percision of the instruments making the measurements, the totals do not always add to 100 percent. In those cases, an adjustment to the percentage of each component must be made. Table 3 shows a gas sample where the components do not add up to 100 percent and the method used to correct the tabel values.

Table 3
Example Gas Sample Adjustment

Component	Measured Mole %	Adjusted Mole %
Methane	78.20	78.61
Ethane	3.66	3.68
Propane	3.40	3.42
I-C4	1.84	1.85
N-C4	1.62	1.63
I-C5	1.65	1.66
N-C5	1.22	1.23
C6	1.88	1.89
C7	0.91	0.91
C8	0.82	0.82
C9	0.25	0.25
C10	0.14	0.14
O2	0.00	0.00
N2	2.44	2.45
CO2	1.30	1.31
H2S	0.00	0.00
Ar	0.15	0.15
Total	99.48	100.00

Notes:
Adjusted Mole% = Measured Mole % / Total Measured Mole %

The adjusted mole percentages are just the measured mole percentages divided by the total of the measured mole percentages. When the total of the measured mole % is 98 percent or greater, this method can be used with fair accuracy. If the sum is less than 98 percent, the accuracy of this method decreases and might warrant an new gas sample.

Calculating the gas properties of the sampled gas is done by combining the results of the gas sample with the properties shown in Table 1. For the purpose of showing how to calculate gas properties of a gas sample, we will use the gas sample shown in Table 2. Table 4 on the next page combines the mole percentages of the gas sample in Table 2 and the properties of each component from Table 1 into a single table.

Table 4
Gas Composition from Table 2 and Gas Properties from Table 1

Component	Mole Fraction (%)	Molecular Weight	Critical Pressure (psia)	Critical Temperature (°R)	Heating Value (btu/scf)	Liquid Hydrocarbon Volume (scf/gal)
Methane	79.28	16.042	667.00	343.01	1010.0	59.138
Ethane	3.55	30.069	706.60	549.59	1769.7	37.503
Propane	3.43	44.096	615.50	665.59	2516.2	36.404
Iso-Butane	1.80	58.122	527.90	734.08	3252.0	30.644
N-Butane	1.54	58.122	550.90	765.22	3262.4	31.794
Iso-Pentane	1.66	72.149	490.40	828.67	4000.9	27.390
N-Pentane	1.30	72.149	488.80	845.47	4008.7	27.676
Hexane	1.92	86.175	436.90	913.47	4756.0	24.380
Heptane	0.88	100.202	396.80	972.57	5502.5	21.729
Octane	0.75	114.229	360.70	1,023.87	6248.9	19.582
Nonane	0.00	128.255	330.70	1,070.47	6996.4	17.807
Decane	0.00	142.282	304.60	1,111.87	7743.0	16.323
Air	0.00	28.959	551.90	238.70	0.0	0.000
Nitrogen	2.44	28.014	492.50	227.14	0.0	0.000
Oxygen	0.00	31.999	731.40	278.24	0.0	0.000
Carbon Dioxide	1.30	44.010	1,070.00	547.45	0.0	0.000
Hydrogen Sulfide	0.00	34.082	1,306.50	672.48	637.1	0.000
Hydrogen	0.00	2.016	190.70	59.77	324.2	0.000
Argon	0.15	39.948	705.32	271.24	0.0	0.000
Helium	0.00	4.003	33.00	9.35	0.0	0.000
Total	**100.00**					

To determine the properties of the gas sample, we will now add some columns to Table 4 so we can calculate the mole percentage weighted properties of each component. Table 5 shows the additional columns where the weighted values are tabulated and accumulated. To calculate the mole weighted value of each property, multiply the value for that property by the mole percentage for the given component. This table can be created manually, or it can be created using a spreadsheet program.

In this example, the mole percentage for ethane is 3.55%. The value for the critical pressure of ethane is 706.6 psia. Multiplying 706.6 psia by 3.55% give a mole weighted value of 25 psia as shown in mole weighted critical pressure column for ethane. Once we have calculated the mole weighted values for each component in the gas sample, the values are summed to arrive at the properties for the gas sample.

For this sample, the gas sample molecular weight is 24.08. the critical pressure is 649.05 psia, the critical temperature is 410.87 ^{o}R, the heating value is 1,364 btu per standard cubic feet, and the liquid yield in a gas plant with ethane removal capability is 5.612 gallons per thousand cubic feet. The removal of natural gas liquids will be discussed in more detail later in this course.

Table 5
Calculation of Mole Fraction Weighted Properties

							Mole Fraction Weighted				
Component	**Mole Fraction (%)**	**Molecular Weight**	**Critical Pressure (psia)**	**Critical Temperature (^{o}R)**	**Heating Value (btu/scf)**	**Liquid Hydrocarbon Volume (scf/gal)**	**Molecular Weight**	**Critical Pressure (psia)**	**Critical Temperature (^{o}R)**	**Heating Value (btu/scf)**	**Liquid Hydrocarbon Content (gal/Mscf)**
Methane	79.28	16.042	667.00	343.01	1010.0	59.138	12.72	528.80	271.94	801	0.000
Ethane	3.55	30.069	706.60	549.59	1769.7	37.503	1.07	25.08	19.51	63	0.947
Propane	3.43	44.096	615.50	665.59	2516.2	36.404	1.51	21.11	22.83	86	0.942
Iso-Butane	1.80	58.122	527.90	734.08	3252.0	30.644	1.05	9.50	13.21	59	0.587
N-Butane	1.54	58.122	550.90	765.22	3262.4	31.794	0.90	8.48	11.78	50	0.484
Iso-Pentane	1.66	72.149	490.40	828.67	4000.9	27.390	1.20	8.14	13.76	66	0.606
N-Pentane	1.30	72.149	488.80	845.47	4008.7	27.676	0.94	6.35	10.99	52	0.470
Hexane	1.92	86.175	436.90	913.47	4756.0	24.380	1.65	8.39	17.54	91	0.788
Heptane	0.88	100.202	396.80	972.57	5502.5	21.729	0.88	3.49	8.56	48	0.405
Octane	0.75	114.229	360.70	1,023.87	6248.9	19.582	0.86	2.71	7.68	47	0.383
Nonane	0.00	128.255	330.70	1,070.47	6996.4	17.807	0.00	0.00	0.00	0	0.000
Decane	0.00	142.282	304.60	1,111.87	7743.0	16.323	0.00	0.00	0.00	0	0.000
Air	0.00	28.959	551.90	238.70	0.0	0.000	0.00	0.00	0.00	0	0.000
Nitrogen	2.44	28.014	492.50	227.14	0.0	0.000	0.68	12.02	5.54	0	0.000
Oxygen	0.00	31.999	731.40	278.24	0.0	0.000	0.00	0.00	0.00	0	0.000
Carbon Dioxide	1.30	44.010	1,070.00	547.45	0.0	0.000	0.57	13.91	7.12	0	0.000
Hydrogen Sulfide	0.00	34.082	1,306.50	672.48	637.1	0.000	0.00	0.00	0.00	0	0.000
Hydrogen	0.00	2.016	190.70	59.77	324.2	0.000	0.00	0.00	0.00	0	0.000
Argon	0.15	39.948	705.32	271.24	0.0	0.000	0.06	1.06	0.41	0	0.000
Helium	0.00	4.003	33.00	9.35	0.0	0.000	0.00	0.00	0.00	0	0.000
Total	**100.00**						**24.08**	**649.05**	**410.87**	**1,364**	**5.612**

Now that the properties for the gas sample have been calculated, we can use these values to determine some useful results.

Specific Gravity

The specific gravity of gas is the weight of the gas relative to the weight of air. Once the molecular weight of the gas sample is known, we can simply divide it by the molecular weight of air to obtain its specific gravity. As mentioned previously, the specific gravity of a gas is important in estimating the gas deviation factor needed to adjust the Ideal Gas Law for hydrocarbon gases. The specific gravity is calculated as follows.

$$Specific\ Gravity = \frac{Molecular\ Weight\ of\ Gas\ Sample}{28.959}$$

Natural Gas Units

The standard units for measurement, production, and transmission of natural gas are thousand standard cubic feet (Mscf) and million standard cubic feet (MMscf). Pricing for natural gas is expressed in units of heat for one thousand British Thermal Units (Mbtu). The price basis is usually 1,000 Mbtu/Mscf for gas pricing. To adjust the price for btu content of the gas, multiply the price times the heating content (in Mbtu/Mscf) and divide by 1,000 to get the price per Mscf of gas as shown below.

$$Price\ per\ Mcf = Gas\ Price * \frac{Heating\ Content}{1{,}000}$$

Natural Gas Liquids

Notice in the last column of Table 5, the units of natural gas liquids are listed as gallons per thousand standard cubic feet (gal/Mscf), while in column 7, the liquid content is shown in units of standard cubic feet per gallon (scf/gal), which is the inverse of liquid yield. Natural gas liquids are normally priced and sold in barrels. Natural gas liquids are normally expressed as a liquid yield in units of barrels per million standard cubic feet (bbl/MMscf). To convert the natural gas liquid content from gal/Mscf to bbl/MMscf, use the following formula.

$$Liquid\ Yield\ in\ barrels\ per\ MMscf = 1000 * \frac{Liquid\ Content\ in\ gal\ per\ Mscf}{42}$$

Gas that contains very little liquid is known as “dry gas”, while one that contains higher amounts of liquids is known as “wet gas”. There is no official definition of when a gas is “dry” or “wet”. A gas sample that calculates only a few barrels per million standard cubic feet of gas would likely be classified as a “dry gas”. Wet gas must be processed through a gas plant to remove the liquids. A gas plant is a facility that is designed specifically to separate the various components in a gas for the natural gas market.

Unless the gas is being liquified for overseas transport (known as Liquified Natural Gas or LNG), the methane portion of natural gas is transported and sold as a gas. If the ethane content is low, it may be more costly for a gas plant to remove the ethane than its sales price. When ethane is removed from the natural gas, it is liquified. Small ethane content usually dictates that it be combined with methane and sold as a gas. These determinations are economic ones and not within the scope of this discussion. However, it should be noted that if the ethane content is greater than 5 percent, it is usually removed and liquified.

During production of gas, the pressure and temperature of the gas is significantly reduced from the pressure and temperature that occur at reservoir conditions. During this reduction in pressure and temperature, some portion of the gas will liquify within the production separators and tanks. This liquid produced in the field is referred to as condensate. As a rule, condensate is composed of alkanes of heptane and above which is sometimes referred to as C7+ (heptane contains 7 carbon atoms). Condensate content can be determined by summing the heptane thru decane liquid yield from a table such as Table 5.

In the case of gas being processed by a gas plant, the plant usually removes the ethane thru hexane components. In a case where the inlet pressure has been kept quite high, all components may be removed by a gas plant (including the C7+ components). The analysis of the gas sample as shown in Table 5 is entirely useful in determining the liquid yield, and hence the revenue that can be derived from processing the gas through a gas plant.

The information obtained from a table like Table 5 can be used to estimate the volume of non-hydrocarbons that must be removed from the gas. The information contained in Table 5 can be used to determine the most optimum way to design the gas plant.

Shrinkage of Natural Gas

Shrinkage is defined as the amount of loss in volume that occurs between the natural gas being produced and the amount of gas being sold. There are several points in the gas production and processing phases than can lead to shrinkage of the gas volumes. Shrinkage occurs for the following reasons:

- Gathering system leakage
- Gas plant fuel
- Removal of natural gas liquids (including condensate)
- Removal of non-hydrocarbons

The shrinkage of gas volume due to the removal of gas plant liquids and non-hydrocarbons can be directly calculated from a table like Table 5. The amount of volume reduction due to plant fuel and gathering system losses (which can include fuel for compressors) is usually fairly constant for a production system. These additional losses usually account for 5 percent or less of the total produced gas entering the system.

Shrinkage is the cumulative loss of gas volume at any point in the gas flow stream. It can be easily calculated as:

$$Shrinkage\ \% = 100 * \frac{Initial\ Gas\ Quantity - Gas\ Quantity\ at\ Any\ Point}{Initial\ Gas\ Quantity}$$

Operating Considerations

A company producing natural gas contracts the sale of the gas to either an end user or gas plant for processing. The gas plant can be an independent operator or can be the operator of wells from which the gas is produced. If the gas is sold directly to the end user, it is sold in gaseous form and the price of the gas is based on its heating value. The price of the gas may also be adjusted based on the type of non-hydrocarbons or the percentage of non-hydrocarbons.

Gas that is sold to a gas plant can be sold "as is" or sold after plant processing. There are an infinite number of gas contracts that can be negotiated for the sale of gas to a gas plant. A typical gas contract would be for the gas plant to use some of the gas for fuel to operate the plant, remove the non-hydrocarbon and liquid portions of the gas, and have the plant keep a portion of the natural gas liquids as payment for the processing of the gas. Other common contracts are for the gas plant to charge a processing fee and sell all the gas and natural gas liquids for the gas producer.

Gas sold into pipelines owned and operated by residential gas companies consists almost entirely of methane with small amounts of ethane. Contracts for the transmission of residential gas specify the amount of non-hydrocarbon components that can be present in the gas. The amount of non-hydrocarbon components is usually in the 1 to 2 percent range or less.

Although this course is not concerned with the design of gas processing plants, it should be mentioned that the recovery of lighter natural gas liquids (ethane, propane, and butane) is rarely 100%. Gas plants are optimized based on the average natural gas content entering the gas plant. As time progresses and new wells are added to the inlet stream (and older ones removed), the concentration of the various natural gas components changes. The operation of these plants allows for slight changes in concentration of the various components, but only to a certain degree. When the lighter liquids are not fully removed, the remaining volume gets entrained in the gas stream exiting the plant. The exiting gas stream benefit by having an increased heating value of the slight addition of these lighter liquid components. For the purpose of this course, we will assume a 100% recovery of liquids.

Example Problem:

Let's see how we can use the calculations made in Table 5 to solve the following:

The gas sample in Table 5 is representative of gas that will be produced. This gas will pass through surface production facilities that will remove the C7+ portion of the gas. Subsequent to that, the gas will enter into a gathering system with an average 2% loss of gas due to leakage. The gas is under a contract to remove liquids except ethane. The plant is also designed to remove non-hydrocarbons. Assume no gas losses for plant fuel under the processing contract. The methane and ethane exiting the plant will be sold into a pipeline. The table below lists the contract prices for the various products.

Product	Price
Methane	$ 2.72 per Mbtu
Ethane	$ 18.55 per bbl
Propane	$ 24.65 per bbl
Butane	$ 33.50 per bbl
Pentane+	$36.75 per bbl
C7+	$41.00 per bbl

1. What is the specific gravity of the gas?
2. What is the volume C7+ produced per MMscf of produced gas?
3. What is the volume of natural gas liquids recovered by the gas plant per MMscf of produced gas?
4. What is the shrinkage of the produced gas to sales gas volume?
5. What is the btu content of the sales gas?
6. What is the price per Mscf of the sales gas?
7. What is the total revenue of natural gas liquids derived from 1 Mscf of produced gas?
8. What is the total revenue derived from 1 Mscf of produced gas?

Answers:

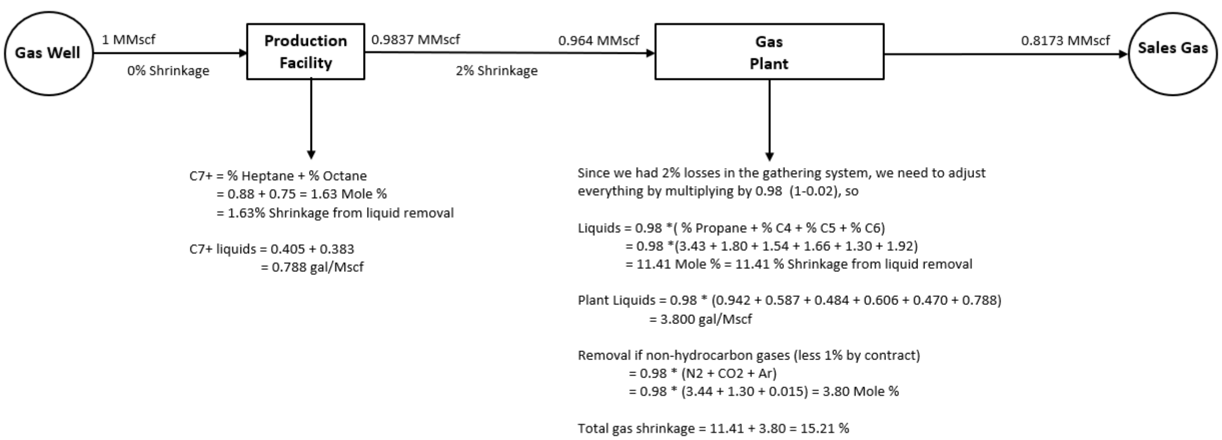
1. The specific gravity is calculated as:

   Specific Gravity = 24.08 / 28.959 = 0.832

   The most efficient way to calculate the answers to questions 2 thru 8 is to draw a diagram showing the flow of gas from production thru the plant. Since the gas volumes shrink as the gas flows through the system, this will allow one to see the gas volumes as a percentage of the inlet volume at any point along the way. In the diagram, we can also show the natural gas liquids as they are removed from the gas stream. Figure 1 is a diagram of the gas flow from the gas well thru the gas plant to a gas sales point.

   Figure 1 below is a diagram of the gas flow from the gas well through the production facilities, the gathering system, and the gas plant.

Figure 1



   Notice Figure 1 contains the gas stream, shrinkages, shrinkage due to liquid removal (mole % of the liquids removed), shrinkage due to non-hydrocarbon removal and liquid content.

2. From Table 5 and Figure 1, the liquid content for the C7+ is as follows:
   C7+ = 0.788 gal/Mscf

   To calculate the C7+ liquid content per MMscf, use the equation:

   Liquid Yield in bbl per MMscf = 1000 * Liquid Yield in gal/Mscf / 42
   = 1000 * 0.788 / 42 = 18.76 bbl/MMscf

3. Since there was a 2% shrinkage due to leakage in the gathering system, we must adjust the mole percentages of each remaining gas, and also the liquid yields by multiplying by 98% (0.98). From Table 5 and Figure 1, the liquids removed by the gas plant are

   Plant liquids = 3.800 gal/Mscf

   To calculate the gas plant liquid yield per MMscf, use the equation:

   Liquid Yield in bbl per MMscf = 1000 * Liquid Yield in gal/Mscf / 42
   = 1000 * 3.800 / 42 = 90.47 bbl/MMscf

4. Looking at Figure 1, we see that the sales gas volume is 0.8173 MMscf for each 1 MMscf produced. Therefore, the shrinkage is:

   Shrinkage = 100 * (1 – 0.8173) / 1 = 18.27%

   Another way to do this is to add the mole percentages of methane plus ethane shown in Table 5 and multiply by 0.98 (since we lost 2% due to leakage). This should give the same answer as follows:

   Table 5 methane mole % = 79.28 %, Table 5 ethane mole % = 3.55 %
   Total methane + ethane = 0.98 * (79.28 + 3.55) = 81.73% = 0.8173
   Shrinkage = 100 * (1 – 0.8713) / 1 = 18.27%

5. The btu content of the sales gas is the sum of the percentage of each component of the sales gas multiplied by the btu content for that component. We have to re-adjust the mole percentages of the methane and ethane in the sales gas stream. The percentage of methane and ethane in the final gas mixture is found by using the mole % from Table 5 and readjusting to a 100 percent composition of methane and ethane as follows:

   Table 5 methane mole % = 79.28 %, Table 5 ethane mole % = 3.55 %
   Percentage of methane in sales gas = 100 * 79.28 / (79.28 + 3.55) = 95.71 %
   Percentage of ethane in sales gas = 100 – 95.71 = 4.29 %

   Btu content per Mscf of sales gas = 0.9571 * 1,010 + 0.0429 * 1769.7
   = 1,042.6 Mbtu/Mscf

6. The price for one Mscf of sales gas is the Btu content of 1 Mscf of gas multiplied by the gas price in $/Mbtu as:

   Gas Price = (1,042.6 * 2.72) / 1000 = $2.84 per Mscf

7. To obtain the price for each Mscf of inlet gas, one must calculate the revenue that each component of the gas generates. Perhaps the simplest way to do this is to create a table to keep track of each product and its revenue. Shown below is a table that shows how to perform these calculations:

Calculation of Condensate and Natural Gas Liquid Revenue for 1 Mscf Production

					Mole % Adjusted			
Component	**Mole Fraction (%)**	**Shrinkage Due to Losses (%)**	**Adjusted Mole Fraction (%)**	**Liquid Hydrocarbon Content (scf/gal)**	**Liquid Hydrocarbon Content (bbl/MMscf)**	**Liquid Hydrocarbon Content (bbl/Mscf)**	**Price ($/bbl)**	**Revenue per Mcf Produced Gas ($)**
Propane	3.43	2	3.36	36.404	21.98	0.022	24.65	0.54
Iso-Butane	1.80	2	1.76	30.644	13.71	0.014	33.50	0.46
N-Butane	1.54	2	1.51	31.794	11.30	0.011	36.75	0.42
Iso-Pentane	1.66	2	1.63	27.390	14.14	0.014	36.75	0.52
N-Pentane	1.30	2	1.27	27.676	10.96	0.011	36.75	0.40
Hexane	1.92	2	1.88	24.380	18.38	0.018	36.75	0.68
Heptane	0.88	0	0.88	21.729	9.64	0.010	41.00	0.40
Octane	0.75	0	0.75	19.582	9.12	0.009	41.00	0.37
Nonane	0.00	0	0.00	17.807	0.00	0.000	41.00	0.00
Decane	0.00	0	0.00	16.323	0.00	0.000	41.00	0.00
					109.23	0.109		**3.78**

To calculate the revenue of natural gas liquids requires that the liquid content be adjusted for any losses in the gas stream. Column 3 and 4 adjust the liquid content for the leakage in the gathering system. The hydrocarbon liquid content in bbl/MMscf is divided by 1,000 to get the liquid content in bbl/Mscf and multiplied by the price per barrel to arrive at the revenue for each liquid component. Adding the revenue for each component gives a total of $3.78 per Mscf of produced gas.

Note that the liquid content of the condensate (C7+) and natural gas liquids in bbl/MMscf is the sum of the answers to questions 2 and 3 above:

Total liquids = 18.76 + 90.47 = 109.23 bbl/MMscf

8. The total revenue per Mscf of produced gas is the revenue derived from the sale of methane plus ethane plus the revenue derived from the natural gas liquids, which is the sum of the answers for questions 6 and 7 as shown below:

   Total revenue per Mscf of produced gas = 2.84 + 3.78 = $6.62 per Mscf

Conclusions

The purpose of this course is to show one how to use the analysis of a gas sample to perform various calculations needed by the reservoir, production, and gas processing engineer. The reservoir engineer is interested in using the calculations of the specific gravity, critical pressure, and critical temperature to estimate the volume of gas at various pressures as the reservoir is produced. The production and gas processing engineer will utilize the analysis to design optimal systems for handling and processing the natural gas as it is produced and sold.

As seen in the text and example problems, along with the gas sample analysis, an understanding of the flow of the gas through the various parts of the production system is also required. As shown in the final example problem, a diagram showing the gas flow is a useful method that can be employed to keep track of the gas at various stages in the system. This method is especially good when the systems become more complicated.

After reading this course, one should be able to:

- Have a basic understanding of the Ideal Gas Law
- Understand the various components that comprise natural gas
- Read a gas sample analysis
- Create a table to calculate for the gas sample properties of:
    - Molecular weight
    - Critical Pressure
    - Critical Temperature
    - Heating Value
    - Liquid yield
- Calculate the volume percentage of components in a gas sample
- Calculate the natural gas liquid yield under various assumptions
- Calculate the shrinkage of produced gas at any point in a gas system
- Calculate the heating value of produced gas and gas of differing compositions
- Calculate the shrinkage due to removal of non-hydrocarbon components
- Calculate the revenue that is derived from sale of the various components of natural gas

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