Lecture (3)

Composition of natural gas

Raw natural gas typically consists primarily of methane (CH4), the shortest and lightest hydrocarbon molecule. It also contains varying amounts of:

- Heavier gaseous hydrocarbons: ethane, propane, normal butane, iso-butane, pentanes and even higher molecular weight hydrocarbons. When processed and purified into finished by-products, all of these are collectively referred to NGL (Natural Gas Liquids).
- Acid gases: carbon dioxide (CO_2), hydrogen sulfide (H_2S) and mercaptans such as methanethiol (CH_3SH) and ethanethiol (C_2H_5SH).
- Other gases: nitrogen (N2) and helium (He).
- Water: water vapor and liquid water.
- Liquid hydrocarbons: perhaps some natural gas condensate (also referred to as casing-head gasoline or natural gasoline) and/or crude oil.
- Mercury: very small amounts of mercury primarily in elementary form, but chlorides and other species are possibly present.

Natural gas is considered ***"dry"*** when it is almost pure methane, having had most of the other commonly associated hydrocarbons removed. When other hydrocarbons are present, the natural gas is ***"wet"***. The composition of natural gas varies depending on the field, formation, or reservoir from which it is extracted.

Table 2: Typical Composition of Natural Gas

Name	Formula	Volume (%)
Methane	CH_4	>85
Ethane	C_2H_6	3–8
Propane	C_3H_8	1–2
Butane	C_4H_{10}	<1
Pentane	C_5H_{12}	<1
Carbon dioxide	CO_2	1–2
Hydrogen sulfide	H_2S	<1
Nitrogen	N_2	1–5
Helium	He	<0.5

Classification of Gas Reserve:

1) Proved Reserve (Developed Reserve): Proved reserves are those quantities of gas which, by analysis of geological and engineering data, can be estimated with reasonable certainty to be commercially recoverable, from a given date forward, from known reservoirs and under current economic conditions, operating methods, and government regulations. Proved reserves can be categorized as developed or undeveloped.

2) Probable Reserve (Undeveloped Reserve): Probable reserves are those unproved reserves which analysis of geological and engineering data suggests are more likely than not to be recoverable. In this context, when probabilistic methods are used, there should be at least a 50% probability that the quantities actually recovered will equal or exceed the sum of estimated proved plus probable reserves.

3) Possible Reserve (Undeveloped Reserve): Possible reserves are those unproved reserves which analysis of geological and engineering data suggests are less likely to be recoverable than probable reserves. In this context, when probabilistic methods are used, there should be at least a 10% probability that the quantities actually recovered will equal or exceed the sum of estimated proved plus probable plus possible reserves.

Recovery Estimates During Reservoir Life, there are three periods:

- Period I: This period is before drilling the well, the existence of gas is determined based on geological data.
- Period II: This period is after drilling the well, depending on the well data, the gas volume is determined in the reservoir using the volumetric method.
- Period III: This period depends on the production data. Production is done and future recovery estimated using the material balance method.

Natural Gas Phase Behavior

The natural gas phase behavior is a plot of pressure vs. temperature (Figure 4) that determines whether the natural gas stream at a given pressure and temperature consists of a single gas phase or two phases: gas and liquid.

- **Bubble Point Curve—**the curve that separates the pure liquid (oil) phase from the two-phase (natural gas and oil) region. This means that at a given temperature, when pressure decreases and below the bubble point curve, gas will be emitted from the liquid phase to the two-phase region.
- **Dew Point Curve**—the curve that separates the pure gas phase from the two-phase region. It is the connected points of pressure and temperature at which the first liquid droplet is formed out of the gas phase.
- **Critical Point**—the point on the phase envelope where the bubble point curve meets the dew point curve. At that given pressure and temperature, gas properties are identical to liquid properties. The pressure and temperature at the critical point are called critical pressure and temperature, respectively.
- **Cricondentherm**—the highest temperature at which liquid and vapor can coexist. That means the mixture will be gas irrespective of pressure when the temperature is larger than cricondentherm.
- **Cricondenbar**—the highest pressure at which a liquid and vapor can coexist.

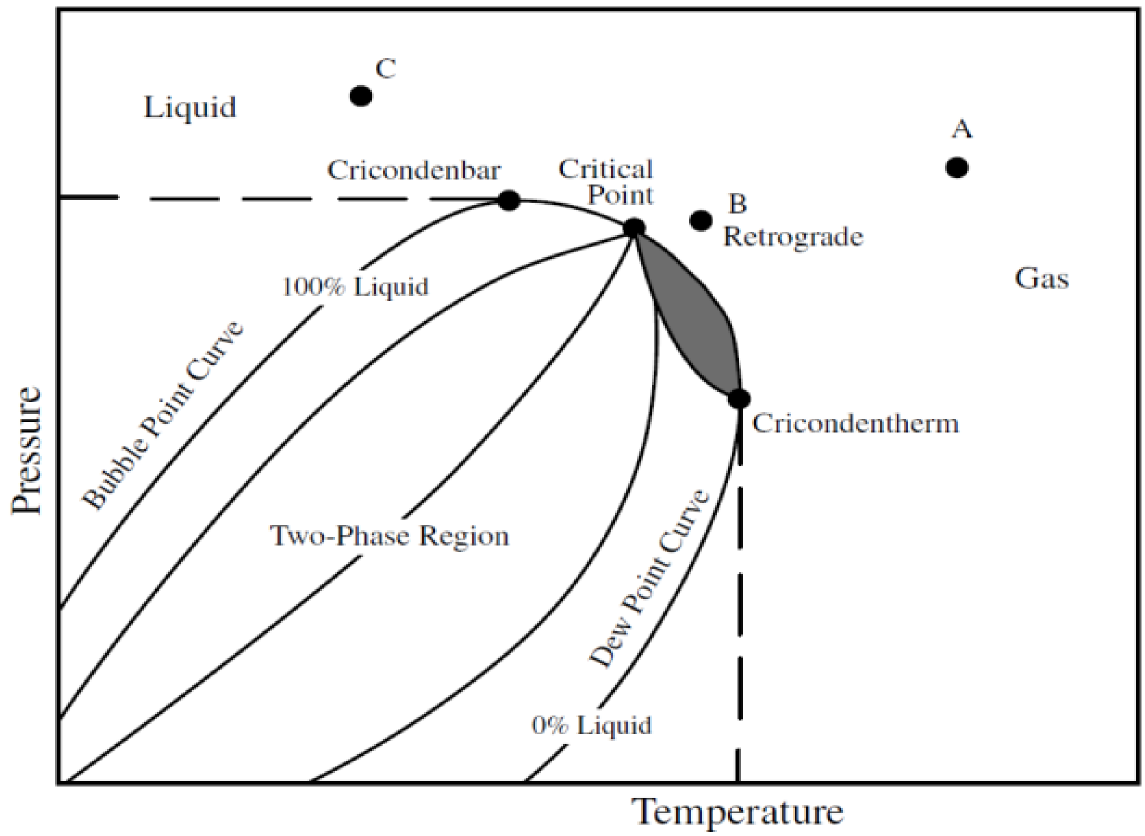

Figure 4: Pressure-Temperature Diagram for A Typical Natural Gas Mixture.

Lecture (4)

IMPURITIES

Natural gases contain impurities in varying amounts. This constitutes serious problems. Therefore, gas treatment required to reduce the impurities to minimum level. Types of Impurities:

1) Carbon dioxide (CO2).

2) Oxygen (O2).

3) Nitrogen (N2).

4) Hydrogen sulfide (H2S).

5) Sulfur compounds.

6) Water (H2O).

7) Helium (He).

8) Mercury (Hg).

9) Dust.

Table 3: Effect of Impurities on Gas Industry

Water vapor	H_2S and CO_2	Liquid hydrocarbons
It is a common impurity. It is not objectionable as such. (a) Liquid water accelerates corrosion in the presence of H_2S gas. (b) Solid hydrates, made up of water and hydrocarbons, plug valves, fittings in pipelines, and so forth.	Both gases are harmful, especially H_2S, which is toxic if burned; it gives SO_2 and SO_3 which are nuisance to consumers. • Both gases are corrosive in the presence of water. • CO_2 contributes a lower heating value to the gas.	Their presence is undesirable in the gas used as a fuel. • The liquid form is objectionable for burners designed for gas fuels. • For pipelines, it is a serious problem to handle two-phase flow: liquid and gas.

Utilization of Natural Gas

Natural gas is one of the major fossil energy sources. When *one standard cubic feet* of natural gas is combusted, it generates *700 Btu to 1,600 Btu* of heat, depending upon gas composition. Natural gas is used as a source of energy in all sectors of the economy. Natural gas provided about 23% of the total world energy supply.

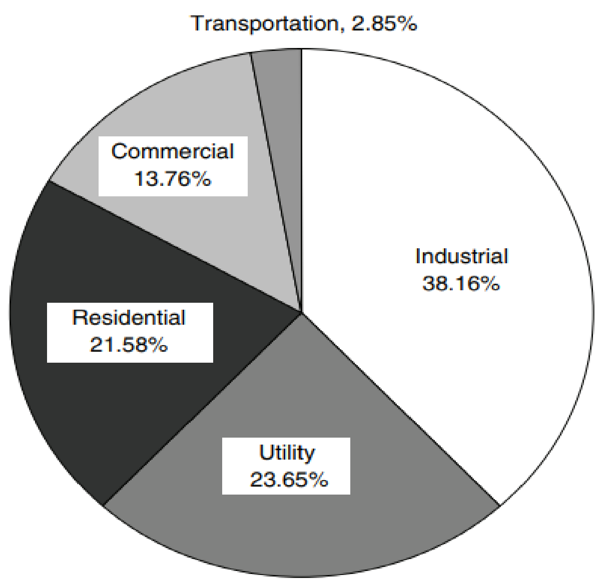

Figure 5: Natural gas is used as a source of energy.

Natural Gas Industry

The consumption of natural gas in all end-use classifications (residential, commercial, industrial, and power generation) has increased rapidly since World War II. This growth has resulted from several factors:

- including development of new markets,
- replacement of coal as fuel for providing space and industrial process heat,
- use of natural gas in making petrochemicals and fertilizers,

- and strong demand for low-sulfur fuels.

Common natural gas unit abbreviations:

Scf = standard cubic foot

Mcf = Thousand Cubic Feet

MMcf = Million Cubic Feet

bbl = Barrel

gal = Gallon

Btu = British Thermal Unit

MMBtu = Million Btu

Dth = decatherm

GJ = gigajoule (metric measure of energy)

toe = tons of oil equivalent

Gas unit conversions:

1 therm = 100,000 Btu

1 Dth = 10 therms

10 therms = 1 MMBtu

1,000,000 Btu = 1 MMBtu

1 Dth = 1 MMBtu

1000 Mcf = 1 MMcf

1000 MMcf = 1 Bcf

1 MMcf = 1,015 MMBtu*

1 GJ = 0.95 MMBtu

1 bbl = 42 gal (U.S. gal)

1 bbl = 34.97 gal (Imperial gal)

1 bbl = 0.136 toe

Irrespective of the source of natural gas, the final specifications set for market sales requirements are usually as given in table 4:

Table 4: Natural Gas Market Sales Requirements

H_2S	0.25–0.3 grain per $100ft^3$ (one grain = 64.799 mg)
Total sulfur	20 grains per 100 ft^3
Oxygen (air)	0.2% by volume
Carbon dioxide	2% by volume
Liquefiable hydrocarbons	0.2 gal per 1000 ft^3
Water content	7 lbs/MMSCF (in a 1000-psia gas line)
Thermal heating value	1150 Btu/ft^3

Heating Value of Gas

The heating value of natural gas is a measure of the amount of heat that is released when the gas is burned. The higher the heating value, the more heat that is released. Natural gas has a high heating value, which makes it an efficient fuel for home heating and other uses.

Heating value is a quantitative measure of heat content of a natural gas. It is experimentally measured using an apparatus called a bomb calorimeter. In such an experiment, a stoichiometric mixture of the gas and oxygen is filled in the bomb calorimeter and then allowed to go through complete combustion.

The higher the Heating Value, the more heat that can be released from a given quantity of natural gas. The Heating Value also affects the price of natural gas. Higher Heating Values mean that more energy can be extracted from a given quantity of natural gas, and this usually results in a higher price for the gas.

The more carbon a fuel has, the more heat it will release when combusted. This is because carbon-carbon bonds are very stable and require a lot of energy to break them apart. Other factors that can affect a fuel's heating value include its moisture content and ash content.

Moisture reduces the heating value because it takes up space in the molecule that could otherwise be used for combustible material. Ash also reduces the heating value because it does not contribute to combustion and actually absorbs some heat during combustion.

1 standard cubic foot (Scf) of natural gas generates 700 Btu to 1,600 Btu of heat, depending upon gas composition.

Power generated = efficiency x power produced $$P_G = \varepsilon * P$$

Gas flow rate, q (Scf/h) $$q = \frac{P}{H} = \frac{P_G}{\varepsilon * H}$$

Gas flow rate, q (Scf/d) $$q = \frac{24 * P_G}{\varepsilon * H}$$

Where, H = heating value (Btu/scf)

Example 1: Natural gas from the Schleicher County, Texas, Straw Reef has a heating value of 1,598 Btu/scf. If this gas is combusted to generate power of 1,000 kW, what is the required gas flow rate in Mscf/day? Assume that the overall efficiency is 50 percent (1 kW = 3,412 Btu/h).

Solution:

Output power of the generator:

1,000 kW = (1,000 kW) (3,412 Btu/h per kW)

$= 3.412 \times 10^6$ Btu/h $= 8.19 \times 10^7$ Btu/day

Fuel gas requirement:

$(8.19 \times 10^7$ Btu/day)/(1,598 Btu/scf)*(0.5)

$= 1.025 \times 10^5$ scf/day = 102.49 Mscf/day

Example 2: Natural gas with a heating value of 1,400 Btu/scf is used to generate 2000 kW of electricity at a rate of 0.292 MMscf/day. What is the overall efficiency (1 kW = 3412 Btu/h)?

Solution:

Output power of the generator:

2,000 kW = (2,000 kW) (3,412 Btu/h per kW)

$= 6.824 \times 10^6$ Btu/h $= 163.776 \times 10^6$ Btu/day

Fuel gas requirement:

$0.292 * 10^6$ (scf/day) $= 163.776 \times 10^6$ Btu/day / (ε * 1400 Btu/scf)

$\boldsymbol{\varepsilon = 0.40 = 40}$ %

Problems

1) Natural gas from the Morgan County, Colorado, D-Sand, has a heating value of 1,228 Btu/scf. If this gas is combusted to drive a gas turbine for a gas compressor of 1,000 hp, what is the required gas flow rate in MMscf/day? Assume that the overall efficiency is 30% (1 hp = 2,544 Btu/h).
2) Natural gas from the William County, North Dakota, Red River formation, has a heating value of 1,032 Btu/scf. If this gas is used to generate electricity at a rate of 1 MMscf/day, how many watts of electricity would the generator produce if the overall efficiency is 50% (1 hp = 745 W)?
3) Natural gas from the William County, North Dakota, Red River formation, has a heating value of 1,032 Btu/scf. If this gas is used to generate electricity at a rate of 1 MMscf/day, how many watts of electricity would the generator produce if the overall efficiency is 50% (1 kW = 3412 Btu/h)?