Tikrit University

The College of Petroleum Processes Engineering

Petroleum Systems Control Engineering Department

Properties of Petroleum & Natural Gas

Third Class

Lecture 17

By

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Natural Gas (NG)

- Natural gas is a fossil fuel formed when layers of buried plants, gases, and animals are exposed to intense heat and pressure over thousands of years, It is a subcategory of petroleum that is a naturally occurring, complex mixture of hydrocarbons, with a minor amount of inorganic compounds. Table 1 shows composition of a typical natural gas.
- Natural gas is the gas obtained from natural underground reservoirs either as free gas or gas associated with crude oil. It generally contains large amounts of methane (CH_4) along with decreasing amounts of other hydrocarbons. Impurities such as H_2S, N_2, and CO_2 are often found with the gas. It also generally comes saturated with water vapor.

Table 1 shows composition of a typical natural gas.

Major Hydrocarbon Components of "Typical" Natural Gas		
Methane	C_1	65% to above 95%
Ethane	C_2	2% to 15%
Propane	C_3	0.25% to 5%
Butane	C_4	≈0 to 5%
Pentane	C_{5+}	0.05% to 2%
Non-hydrocarbon Components produced with Natural Gas		
Nitrogen	N_2	≈0 to 20%
Hydrogen sulfide	H_2S	≈0 to above 15%
Carbon dioxide	CO_2	≈0 to above 20%

- Natural gas often contains hydrogen sulfide and carbon dioxide in concentrations, which make the gas unsuitable for use as fuel. The gas may also contain other sulfur materials, which must be removed before the gas can be utilized as fuel. Gas which is produced during the refining of crude oil often contains complex sulfur compounds which must be removed before the gas can be used for fuel.
- Natural gas is the most sought after fuel source because of its clean combustion (reduction of the atmosphere pollution). It is also a base for LPG (propane, butane) manufacture. It can be used also as a feedstock to petrochemical plants.
- Production and distribution of natural gas are non-negligeable agents of the world economy.
- Natural gas or associated gas produced with crude oil-contain acid components, mainly carbon dioxide (CO_2) and hydrogen sulfide (H_2S) and sometimes traces of other compounds: Carbonyl sulfide (COS) carbon disulfide (CS_2) and mercaptans.

TABLE 2

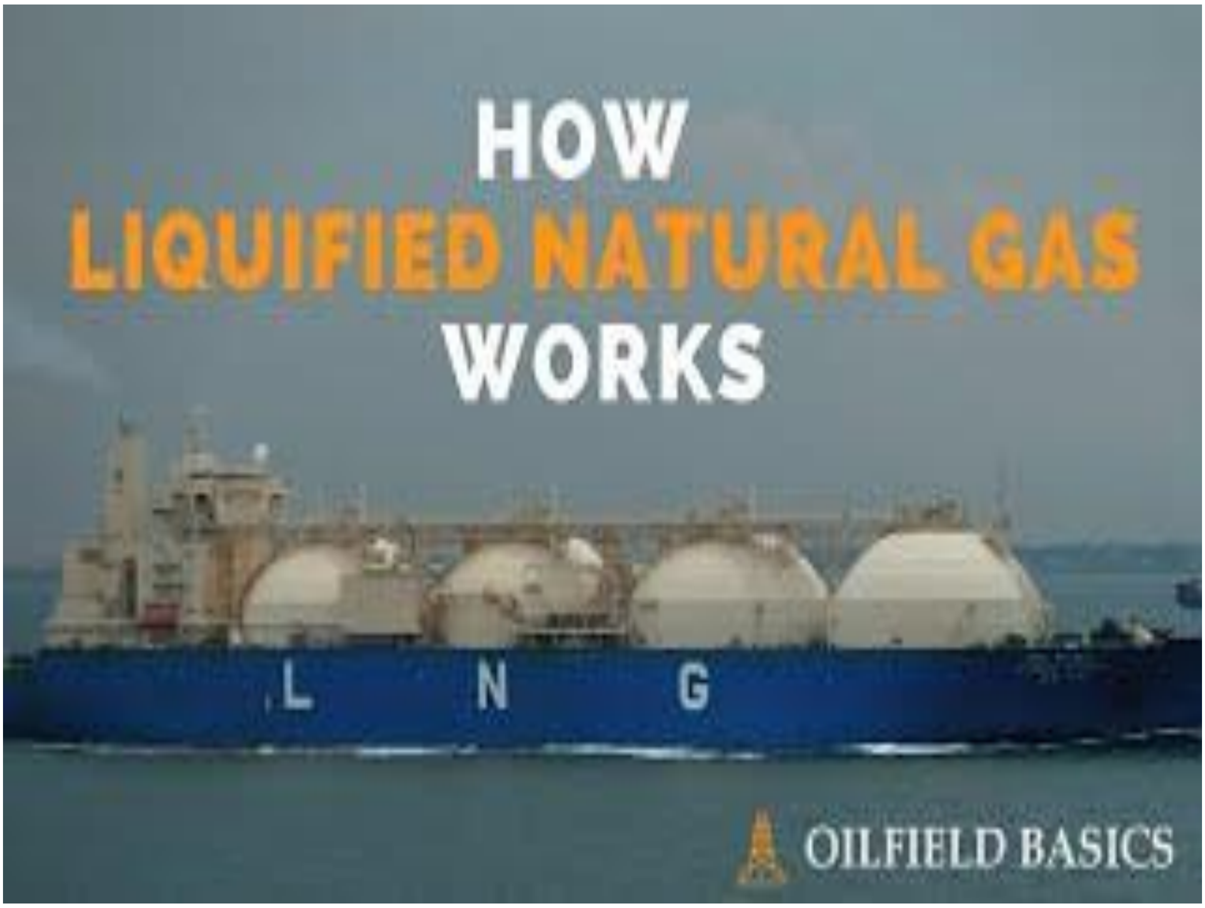
COMPOSITIONAL ANALYSIS OF NATURAL GASES

(From Natural Reservoirs)

Country	Iran				
Field	**Kangan**	**Nar**	**Khangiran**	**Assaluyeh**	**Sarkhon**
Components	**Mole%**	**Mole%**	**Mole%**	**Mole%**	**Mole%**
N_2	5.95	4.61	0.55	3.474	4.89
CO_2	1.83	1.46	6.41	1.860	0.65
H_2S	681 ppm	59.6 ppm	3.85	0.555	0.02
COS	---	---	17 ppm	3.1 ppm	---
C_1	85.29	87.98	88.35	85.086	87.76
C_2	4.14	3.65	0.56	5.448	3.75
C_3	1.32	1.09	0.09	1.991	1.39
IC_4	0.29	0.24	0.02	0.379	0.32
NC_4	0.40	0.32	0.03	0.573	0.48
IC_5	0.20	0.16	0.02	0.178	0.19
NC_5	0.14	0.11	0.02	0.159	0.15
C_6+	0.44	0.38	0.01	0.273	0.21
RSH	59.6 ppm	17.1 ppm	---	159.4 ppm	---

Liquefied natural gas (LNG)

- When natural gas is cooled to a temperature of approximately −260 °F (−160 °C) at atmospheric pressure it condenses to a liquid called liquefied natural gas (LNG).
- One volume of this liquid takes up about 1/600th the volume of natural gas at a stove burner tip.
- LNG is only about 45% the density of water.
- LNG is odorless, colorless, non-corrosive, and non-toxic.
- When vaporized it burns only in concentrations of 5% to 15% when mixed with air.
- Neither LNG, nor its vapor, can explode in an unconfined environment.



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 **(C_2H_6)**, propane **(C_3H_8)**, normal butane **($n\text{-}C_4H_{10}$)**, iso-butane **($i\text{-}C_4H_{10}$)**, pentanes and even higher molecular weight hydrocarbons. When processed and purified into finished by-products, all of these are collectively referred to as **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 **(N_2)** 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.

The composition of natural gas varies depending on the field, formation, or reservoir from which it is extracted.

Table 3: 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

Liquid petroleum gas (LPG)

- Sometimes called **propane** is often confused with LNG and vice versa. They are not the same and the differences are significant.
- Varieties of LPG bought and sold include mixes that are primarily propane, mixes that are primarily butane, and mixes including propane, propylene, n-butane, butylene and iso-butane.
- Depending on the season—in winter more propane, in summer more butane. Vapor pressures, at 30°C, are for commercial propane in the range 10-12 barg (1 to 1.2 MPa), for commercial butane, 2-4 barg (0.2 to 0.4 MPa). In some countries LPG is composed primarily of propane (upwards to 95%) and smaller quantities of butane.

General Definitions

- **Pipeline Gas** is the gas which has the quality to be used as a domestic or industrial fuel. It meets the specifications set by a pipeline transmission company, and/or distributing company.
- **Sour Gas:** Gas that contains more than 1 grain of H_2S/100 SCF
- **Sweet Gas:** Gas in which the H_2S content is less than 1 grain /100 SCF.
- **Wet Gas:** Gas that contains more than 0.1US gallons of condensates per1000 CF of gas.
- **Dry Gas**: Gas that contains less than 0.1 US gallons of condensates per 1000 CF of gas.
- **Rich Gas**: Gas containing more than 5 to 7 US gallons of compounds heavier than ethane (C3+) per 1000 CF of the gas.
- **Lean Gas**: Gas containing 1 US gallons or less of compounds heavier than ethane (C3+) per 1000 CF of the gas.
- **Pentanes+**: The pentane and heavier fraction of hydrocarbon liquid.
- **Compressed natural gas (CNG):** is natural gas pressurized and stored in welding bottle-like tanks at pressures up to 3,600 psig (25 MPa). Typically, it is same composition of the local "pipeline" gas, with some of the water removed.

Natural gas classification

(A) Conventional natural gas

- Conventional gas is a gas that is trapped in structures in the rock that are caused by folding and/or faulting of sedimentary layers.
- Natural gas from conventional deposits is found in sandstone or limestone formations. These formations are very porous.
- Conventional gas is largely extracted through the drilling of a vertical well from surface into the gas accumulation in porous, permeable gas reservoirs.

There are three types :

- **Nonassociated gas**: is from reservoirs with minimal oil.
- **Associated gas:** is the gas dissolved in oil under natural conditions in the oil reservoir (sometimes called gas-cap gas) or itis free gas in contact with the crude oil , All crude oil reservoirs contain dissolved gas and may or may not contain associated gas.
- **Condensate:** refers to gas with high content of liquid hydrocarbon at reduced pressures and temperatures.

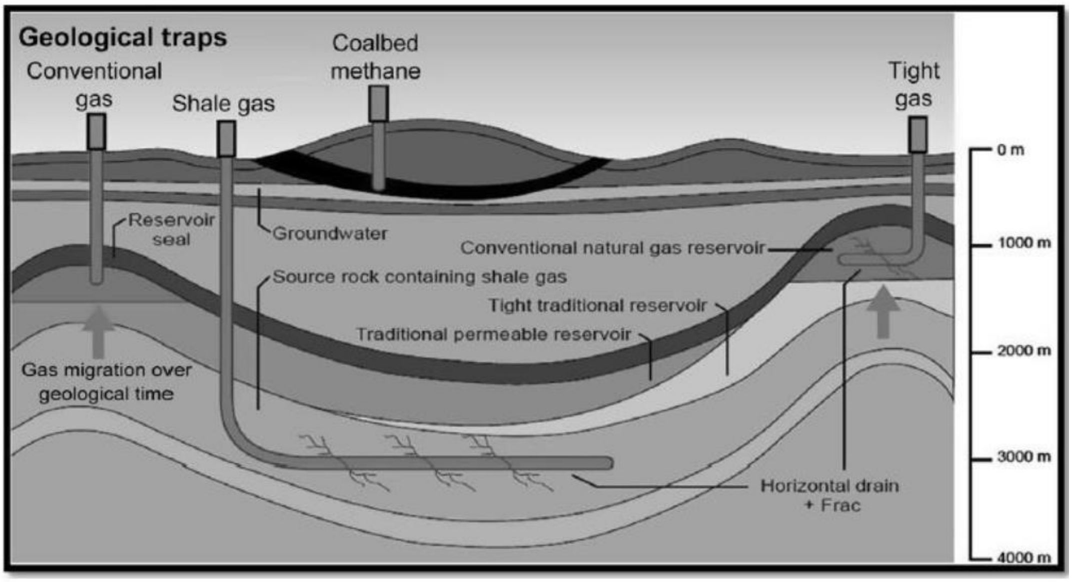
(B) Unconventional natural gas

- Unconventional gas is gas that is trapped in impermeable rock that cannot migrate to a trap and form a conventional gas deposit.
- Unconventional natural gas deposits are difficult to characterize overall, but in general they are often lower in resource concentration, more dispersed over large areas, and require well stimulation or some other extraction or conversion technology.
- To access this unconventional gas, the well is first drilled vertically to reach the required depth and then horizontally through the target unit, More than one horizontal section can be drilled from the one vertical well, increasing exposure to the target layer.

Unconventional gas reservoirs include tight gas, coal bed methane (coal seam gas), gas hydrates, and shale gas.

1. **Coal-Bed Methane (CBM):** This is the generic term given to methane gas held in underground coal seams and released or produced when the water pressure within the seam is reduced by pumping from either vertical or inclined to horizontal surface holes.
2. **Shale Gas:** Large continuous gas accumulations are sometimes present in low permeability shale, (tight) sandstones, siltstones, sandy carbonates, limestone, dolomite, and chalk. Such gas deposits are commonly clas- sified as unconventional, because their reservoir characteristics differ from conventional reservoirs, and they require stimulation to be pro- duced economically.
3. **Gas Hydrates:** A gas hydrate is a molecule consisting of an ice lattice, or "cage," in which low molecular weight hydrocarbon molecules, such as methane, are embedded. The two major conditions that promote hydrate formation are:

- **high gas pressure and low gas temperature.**
- **the gas at or below its water dew point with free water present.**



The main uses of natural gas

- Natural gas is used primarily as a **fuel and as a raw material in manufacturing**.
- It is used in home furnaces, water heaters, and cooking stoves.
- As an industrial fuel, it is used in brick, cement, and ceramic-tile kilns; in glass making; for generating steam in water boilers.
- As a clean heat source for sterilizing instruments and processing foods.
- As a raw material in petrochemical manufacturing. Ethylene, an important petrochemical, is produced from natural gas.
- Natural gas is used to produce hydrogen, sulfur, carbon black, and ammonia. The ammonia is used in a range of fertilizers and as a secondary feedstock for manufacturing other chemicals, including nitric acid and urea.
- Natural gas is considered as **an environmentally friendly clean fuel**, offering important environmental benefits when compared to other fossil fuels.

NATURAL GAS PROPERTIES

Natural gas is colorless, odorless, tasteless, shapeless, and lighter than air. The natural gas after appropriate treatment for acid gas reduction, odorization, and hydrocarbon and moisture dew point adjustment would then be sold within prescribed limits of pressure, calorific value, and possibly Wobbe index (often referred to as the Wobbe number).

Table 4: Properties of Natural Gas

Properties	Value
Relative molar mass	17–20
Carbon content, weight %	73.3
Hydrogen content, weight %	23.9
Oxygen content, weight %	0.4
Hydrogen/carbon atomic ratio	3.0–4.0
Relative density, 15°C	0.72–0.81
Boiling point, °C	−162
Autoignition temperature, °C	540–560
Octane number	120–130
Methane number	69–99
Stoichiometric air/fuel ratio, weight	17.2
Vapour flammability limits, volume %	5–15
Flammability limits	0.7–2.1
Lower heating/calorific value, MJ/kg	38–50
Stoichiometric lower heating value, MJ/kg	2.75
Methane concentration, volume %	80–99
Ethane concentration, volume %	2.7–4.6
Nitrogen concentration, volume %	0.1–15
Carbon dioxide concentration, volume %	1–5
Sulfur concentration, weight % ppm	<5
Specific CO_2 formation, g/MJ	38–50

Gas-Specific Gravity

$$\gamma_g = \frac{M}{M_{air}}$$

Where Mair is the molecular weight of air, which is equal to 28.97. Once we can calculate the value of the molecular weight of the mixture, we can calculate the specific gravity of the mixture. For a gas mixture, we can calculate the molecular weight as

$$M = \sum_{i=1}^{n} y_i M_i$$

Where Mi is the molecular weight of component i, yi is the mole fraction of component i, and n is the total number of components.

So,

$$\gamma_g = \frac{MW_m}{MW_{air}} = \frac{\sum_{i=1}^{n} y_i MW_i}{28.97}$$

Example 1: A natural gas consists of the following (molar) composition: C1 = 0.871, C2 = 0.084, C3 = 0.023, CO_2 = 0.016 and H_2S = 0.006. Calculate the gas gravity to air.

Compound	y_i	MW_i
C_1	0.871	16.04
C_2	0.084	30.07
C_3	0.023	44.09
CO_2	0.016	44.01
H_2S	0.006	34.08
	1	

Solution:

Compound	y_i	MW_i	y_iMW_i
C_1	0.871	16.04	13.971
C_2	0.084	30.07	2.526
C_3	0.023	44.09	1.014
CO_2	0.016	44.01	0.704
H_2S	0.006	34.08	0.204
	1		18.419

the gas gravity is 18.419/28.97 = 0.64.

Gas Density

Gas density is defined as mass per unit volume and so can also be derived and calculated from the real gas law:

$$\rho_g = \frac{m}{V} = \frac{PM}{ZRT}$$

Knowing that the molecular weight of gas is the product of specific gravity and molecular weight of air and that the value of R is 10.73 in field units [8.314 in SI units], we can write the equation for density as

$$\rho_g = 2.7\frac{P\gamma_g}{ZT}$$

where ρ_g is in lbm/ft^3, P is in psia, and T is in °R. Alternately,

$$\rho_g = 3.49\frac{P\gamma_g}{ZT}$$

Example 2: Calculations with real gas law Given the natural gas gravity to air gg = 0.75, the pseudocritical pressure, ppc and temperature, Tpc are 667 psi and 405 R, respectively. If the pressure and temperature are 1,500 psi and 20°F, respectively, calculate how many lb of gas can fit in 1,000 ft^3 of space?

Solution:

For T = 20°F = 480 R

Tpr = 480/405 = 1.19 (which will remain constant).

For p = 1,500 psi

ppr = 1,500/667 = 2.25.

From Figure, Z is obtained as 0.51.

By using the real gas law and gas gravity definition, the mass of gas that can fit in 1,000 ft^3 of space is:

$$m = \frac{pV\gamma_g MW_{air}}{ZRT} = \frac{1{,}500 \times 1{,}000 \times 0.75 \times 28.97}{0.51 \times 10.73 \times 480} = 12{,}408 \text{ lb.}$$

Gas Viscosity

Just as the compressibility of natural gas is much higher than that of oil, water, or rock, the viscosity of natural gas is usually several orders of magnitude lower than oil or water. This makes gas much more mobile in the reservoir than either oil or water. Reliable correlation charts are available to estimate gas viscosity, and the viscosity of gas mixtures at one atmosphere and reservoir temperature can be determined from the gas mixture composition:

$$\mu_{ga} = \frac{\sum_{i=1}^{N} y_i \mu_i \sqrt{M_{gi}}}{\sum_{i=1}^{N} y_i \sqrt{M_{gi}}}$$

where μga is the viscosity of the gas mixture at the desired temperature and atmospheric pressure, *y*i is the mole fraction of the *i*th component, μga is the viscosity of the *i*th component of the gas mixture at the desired temperature and atmospheric pressure, *M*gi is the molecular weight of the *i*th component of the gas mixture, and *N* is the number of components in the gas mixture. This viscosity is then multiplied by the viscosity ratio to obtain the viscosity at reservoir temperature and pressure.

Presence of Nonhydrocarbon Gases

In the presence of large amounts of nonhydrocarbon gases, the gas deviation factor must be adjusted. The pseudocritical properties, Tpc and ppc, can be corrected by:

$$T'_{pc} = T_{pc} - \varepsilon_3,$$

$$p'_{pc} = \frac{p_{pc} T'_{pc}}{T_{pc} + y_{H_2S}(1 - y_{H_2S})\varepsilon_3}$$

where :

y_{H2S} :is the mole fraction of hydrogen sulfide

ε_3: is a function of the H2S and CO2 concentrations, which can be obtained from :

$$\varepsilon = 120\,[A^{0.9} - A^{1.6}] + 15\,(B^{0.5} - B^{4.0})$$

$$A = y_{H_2S} + y_{CO_2}$$

Quality

The amount of energy that is obtained from the burning of a volume of natural gas is measured in British thermal units (Btu). The value of natural gas is calculated by its Btu content.

Wobbe index

- The **Wobbe index** (WI) or **Wobbe number** is an indicator of the interchangeability of fuel gases such as natural gas, liquefied petroleum gas (LPG), and town gas and is frequently defined in the specifications of gas supply and transport utilities.
- Wobbe index (W) is an important criterion of inter-changeability of gases in the industrial applications (engines, boilers, burners, etc).
- Gas composition variation does not involve any notable change of air factor and of flame speed when Wobbe index remains almost constant.
- Wobbe index can be calculated starting from the high heating value (HHV) and specific gas density (d) by

$$W = \frac{HHV}{\sqrt{d}}$$

This parameter is usually used to characterize gas quality

- The Wobbe index is used to compare the combustion energy output of different composition fuel gases in an appliance (fire, cooker etc.). If two fuels have identical Wobbe indices then for given pressure and valve settings the energy output will also be identical. Typically variations of up to 5% are allowed as these would not be noticeable to the consumer.

- Calculate the Wobbe index for a typical fuel. The HHV of natural gas is typically 1,050 Btu / cubic foot and its specific gravity is about 0.59. The Wobbe index for natural gas is therefore about 1,367 Btu / cubic foot.