
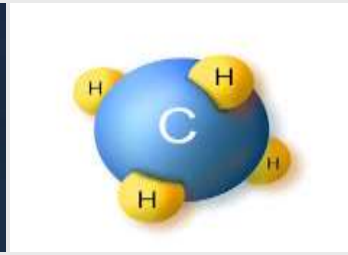


Basic Properties

Natural Gas and LPG’s

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Universiti Teknologi Malaysia
13 August 2016

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Comparison of LPG and natural gas

Item		Natural Gas Before '95	Natural Gas After 95'	LPG
Gas components				
Methane	CH_4 (vol. %)	84.75	92.74	
Ethane	C_2H_6 (vol. %)	10.41	4.07	
Propane	C_3H_8 (vol. %)	0.98	0.77	30
Butane	C_4H_{10} (vol.%)	0.11	0.14	70
Nitrogen	N_2 (vol. %)	0.39	0.45	
Carbon dioxide	CO_2 (vol. %)	3.36	1.83	
Specific gravity	(air = 1)	0.652	0.605	1.926
Specific weight	(kg/Sm^3)	0.799	0.741	2.36
Theoretical oxygen	(m^3/m^3)	2.115	2.045	6.050
Theoretical air	(m^3/ m^3)	10.07	9.738	28.82
	(Sm^3/Kcal)	1.05	1.05	1.03
Calorific value				
Gross	($Kcal/m^3$)	9582	9253	28059
	(Btu/m^3)	38024	36718	111345
	(Kcal/kg)	11992	12487	11889
Net				
	($Kcal/m^3$)	8644	8333	25844
	(Btu/m^3)	34302	33067	102556
		10816	11246	10951
Combustion products	(stoichiometric)			
CO_2	(m^3/m^3)	1.12	1.06	3.7
	(vol. %)	10.1	9.8	11.9
H_2O (vapour)	(m^3/m^3)	2.05	2.01	4.70
	(vol. %)	18.4	18.7	15.1
N_2	(m^3/m^3)	7.96	7.7	22.76
	(vol. %)	71.5	71.5	73.0
Net Wobbe index		10705	10713	18604

Module Objectives

This module is designed and delivered to provide the course participants with the following outcomes:

- The ability to understanding and describe the common terms used in the industry.
- The ability to understand and describe the common properties of hydrocarbon gases.
- The ability to understand and describe the basic principles that govern the characteristics and properties of hydrocarbon gases.
- The ability to realize the significance and implications of those properties in gas systems design and applications, especially wrt to safety.

GAS???

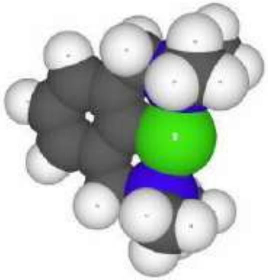
Understanding some common terms

- Natural Gas
- Associated Gas
- Non Associated Gas
- Sales Gas
- LPG
- NGV
- CNG
- LNG
- Town Gas
- Manufactured Gas
- Flue Gases
- Biogas

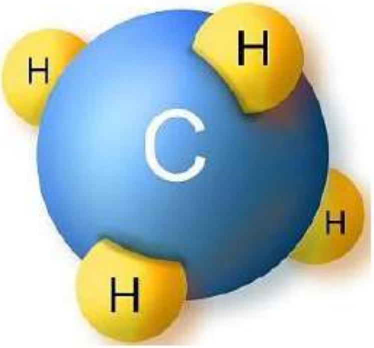
- GPP
- Dehydration
- Sweetening
- Transmission
- Distribution
- Refining
- GTL
- BLEVE

OVERVIEW OF HYDROCARBON CHEMISTRY

Hydrocarbon



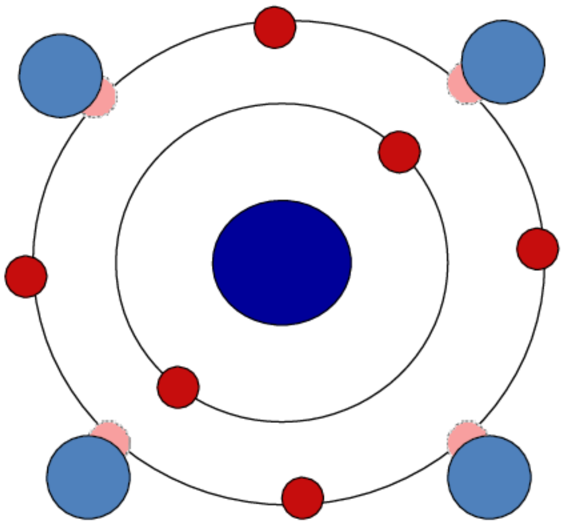
- Crude OIL/GASES – mixtures of many substances mainly compounds of the elements H & C.
  - therefore → HYDROCARBONS
  - non H & C elements also exist
    (eg. S, N, O)
- Processes to manufacture products
  - **Physical** → HC shuffled into useful groups w/o disruption
  - **Chemical/**Conversion → HC broken down and rearranged .



Roles of Carbon in HC Formation

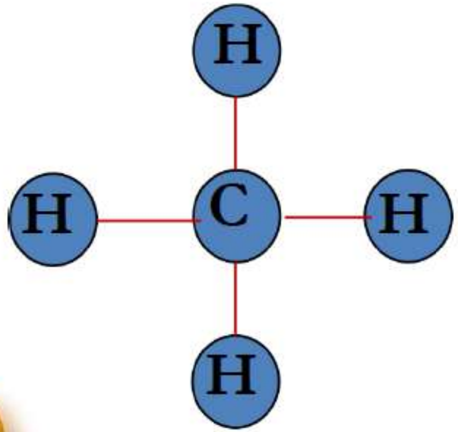
Basic info on Carbon12

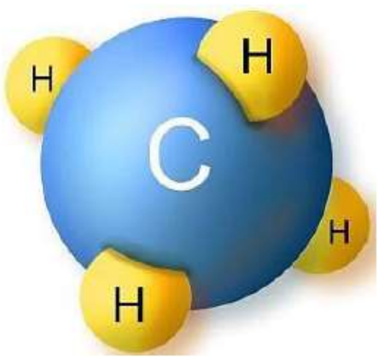
- Constitute of 6 electrons, 6 protons, 6 neutrons
- 2 electrons in first orbit, 4 in second orbit
- 2nd orbit can also have up to eight electrons Therefore valency = 4
- Eg. In the case of the simplest HC, ie methane, since Hydrogen have only one electron, 4 are needed to fill in the outer orbit.



Hydrocarbon

- Maybe gaseous, liquid or solid @ room conditions
  - Up to four C atoms → gaseous
  - Five to twenty C atoms → liquids
  - More than 20 → solids
- Simplest hydrocarbon:
- PONA/PIANO concept to categorize HCs





Methane CH_4

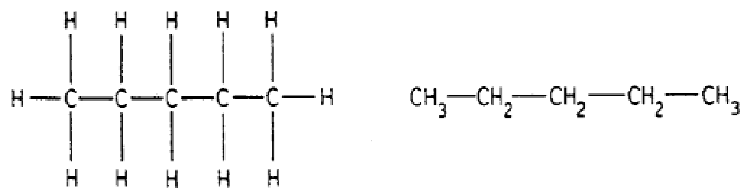
PIANO

A hydrocarbon analysis using gas chromaatograph to determine the propotion of paraffins (P), isoparaffins (I), aromatics (A), naphthalenes (N) and olefins (O) present in petrol or other hydrocarbon fuels

PANO

A hydrocarbon analysis using gas chromaatograph to determine the propotion of paraffins (P), aromatics (A), naphthalenes (N) and olefins (O) present in petrol or other hydrocarbon fuels.

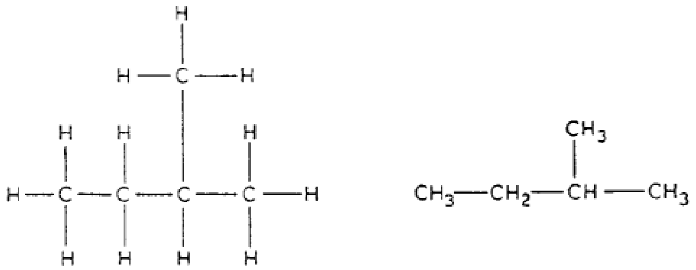
3 Basic Structures

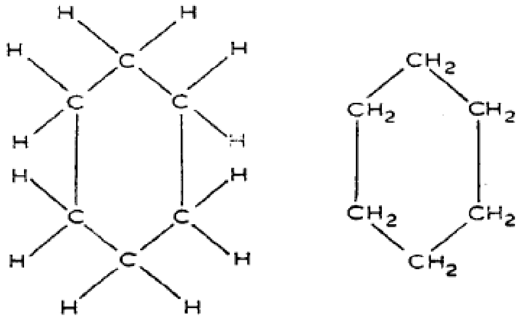


straight-chain hydrocarbon or "normal" compound

Straight chained (normal)

Branched (iso)

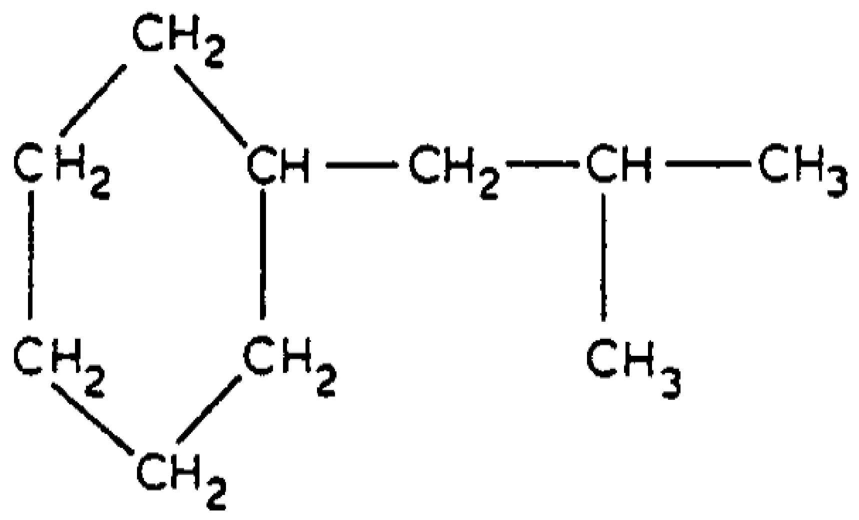




Ring (cyclo, naphtenes)

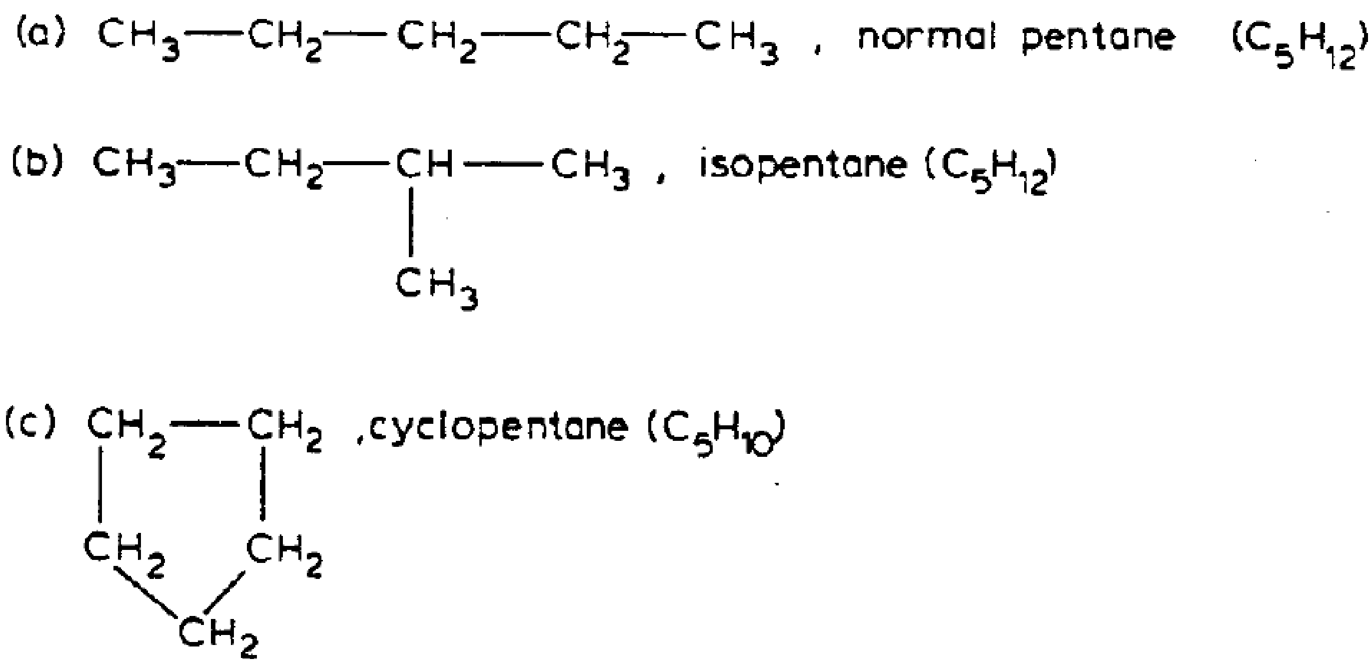
Which can results in …

A combination of chains and ring structures
For example,



Variations name

eg. Pentanes



Unsaturated

Unsaturated hydrocarbons are hydrocarbons that have double or triple covalent bonds between adjacent carbon atoms

- Single double bonds → Olefins
- Two double bonds → Diolefines
- Triple bonds → acetylenes or alkynes

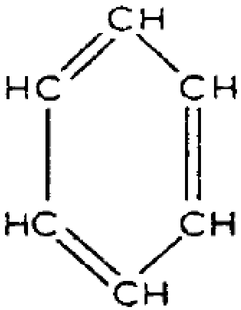
$CH_2{=}CH_2$ ethylene

$CH{\equiv}CH$ acetylene

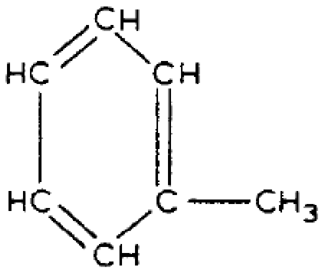
$CH_2{=}CH{-}CH{=}CH_2$ butadiene

Aromatics

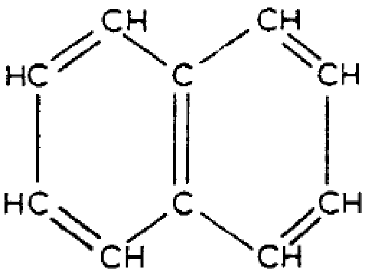
Simplest form



benzene



$C_6H_5CH_3$
toluene



$C_{10}H_8$
naphthalene

More complex molecules of the Aromatic series are obtained by replacing one or more H atoms by HC groups or by `condensing' one or more rings

Non Hydrocarbons

- Although small in quantity, can have adverse effects on final products quality.
- In many cases, are harmful and have noxious effects and must be removed or converted to less harmful products.
- In some cases, they are beneficial and must not be removed or converted
- Eg. Non metals → S, N, O

  Metals → V, Ni, Na, K, Hg

Sulphur Compounds

Corrosive

– Elemental S, H_2S, thiols (mercaptans) of low MW

C_2H_5SH , ethanethiol

Non Corrosive

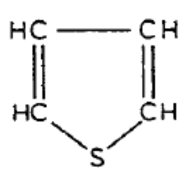
$C_2H_5—S—C_2H_5$, diethyl sulphide

– Sulphides (thioethers)

$C_2H_5—S—S—C_2H_5$, diethyl disulphide

– Disulphides

– & thiophenes



or C_4H_4S , thiophene

Nitrogen Compounds

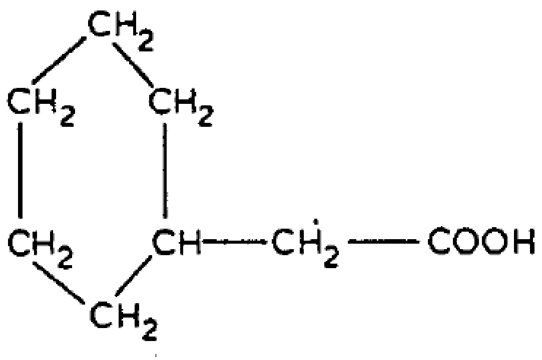
- Most crude contains < 0.1 % wt
- On distillation, give rise to ***nitrogen bases*** in derived products
  - May cause discolouration of heavy gasolines and kerosines
  - Can cause engine fouling and engine oil lacquer if present in gasoline
  - May reduce catalyst activity by increasing coke deposit if present in heavy gas oil feedstocks

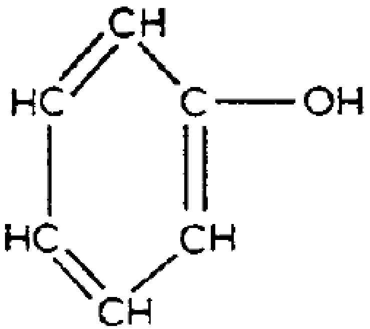
Oxygen Compounds

- On distillation, oxygen compounds decompose to form carboxylic acid group (COOH) in the side chain, for example: ***naphtenic acids***

  These acids are extracted because they form valuable by products used in paint driers, emulsifiers & soaps.

- Other oxygen compounds ***phenols***





phenol

Other Compounds

- Occur in crude as either organic or inorganic compounds
- Remain in the ash on burning
  - Vanadium
  - Nickel
  - Sodium
  - Potassium
  - Copper
  - Zinc

Petroleum Products

- Petroleum products are complex mixtures of aliphatic and aromatic compounds, including sulfur and nitrogen compounds.

- Some of the most common refined petroleum products include methane gas, natural gas liquid or NGL (the ethane and heavier gas components), liquefied petroleum gas or LPG (mostly propane and butane), gasoline (C5-C10), kerosene (C11-C12), diesel fuel (C13-C17), heating oil (C18-C25), and lubricants (C26-C38).

Raw Natural Gas

- Raw natural gas components include the inerts, nitrogen and carbon dioxide, which do not combust. Therefore, they do not contribute to the heating value of the gas, making them undesirable. Trace components commonly include hydrogen sulfide, water vapor, and helium.

- Hydrogen sulfide is highly toxic and is characterized by a very strong, foul odor. It is also referred to as sour gas.

- Helium is a true inert gas that is nonreactive with other compounds. Other less common trace components include oxygen, hydrogen, and carbon monoxide. For Malaysian NG, Hg presence is a common problem.

STATE OF MATTERS (REVIEW)

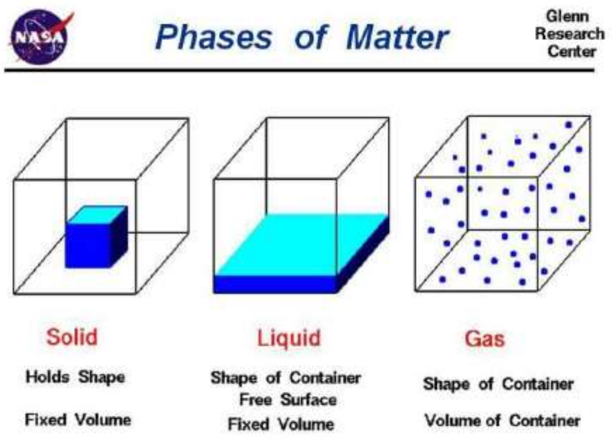
States of Matter (Review)

Traditionally, matter is thought to exists mainly in three physical states--gas, liquid, and solid. More recent studies have identified the fourth – **plasma**.

- **Solids:** Rigid and have definite shapes. The volume it occupies does not vary much with changes in T and P. ie. **V ≠ f(T,P)**

- **Liquid**: Flows and assumes the shape of its container. Generally, incompressible ie.
  V ≠ f(P)

- **Gases**: Occupy all parts of any vessel in which they are confined. Capable of infinite expansion and are easily compressed. They consist primarily of empty space because the individual particles are so far apart. **V = f (P,T)**



In general, the behavior of gases are described through the relationships between P, V and T, PVT for short, or the Gas Laws/ Equation of States (EOS) Eg. PV = znRT

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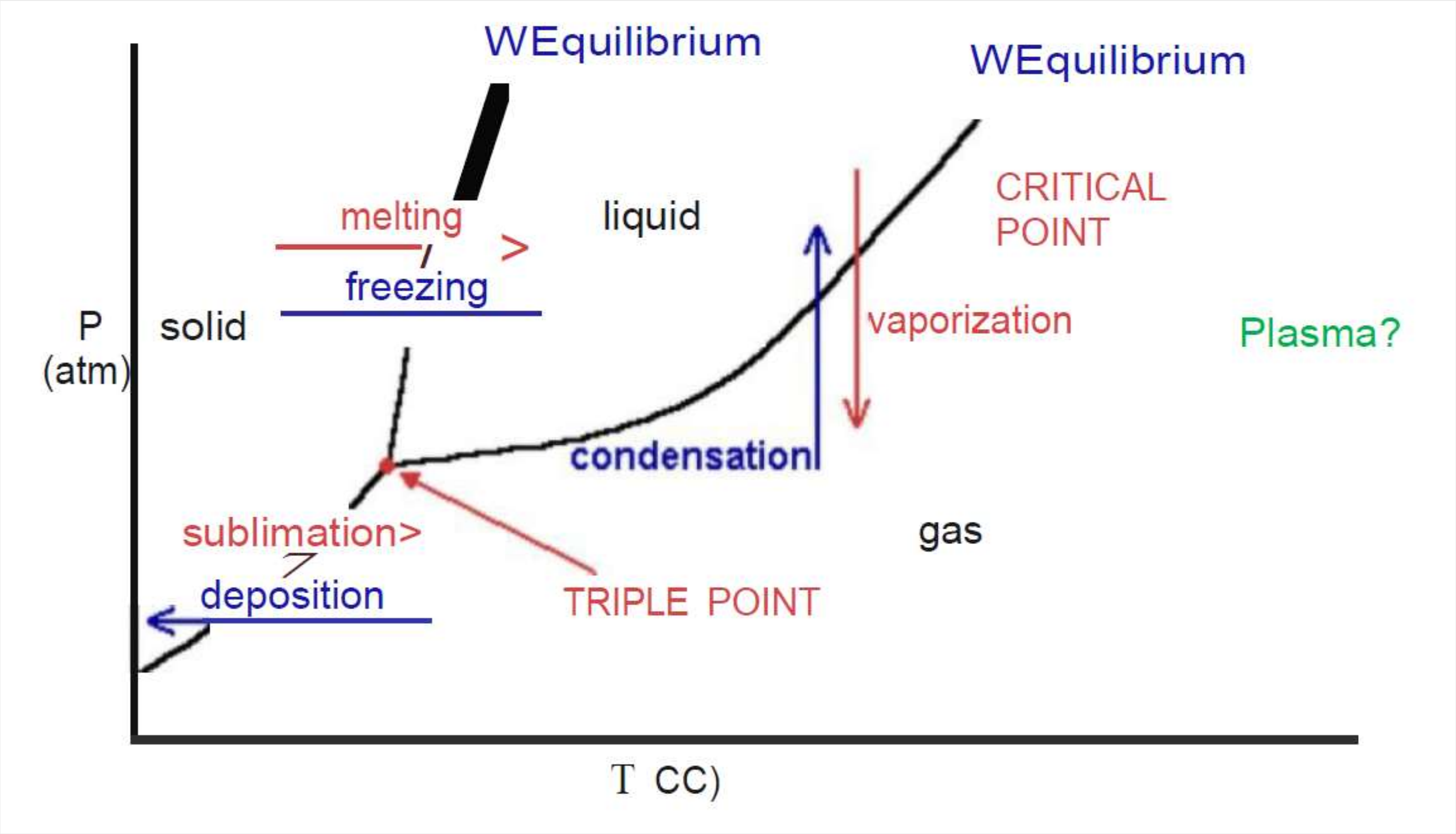
Phase Diagram



Gas Law Fundamentals

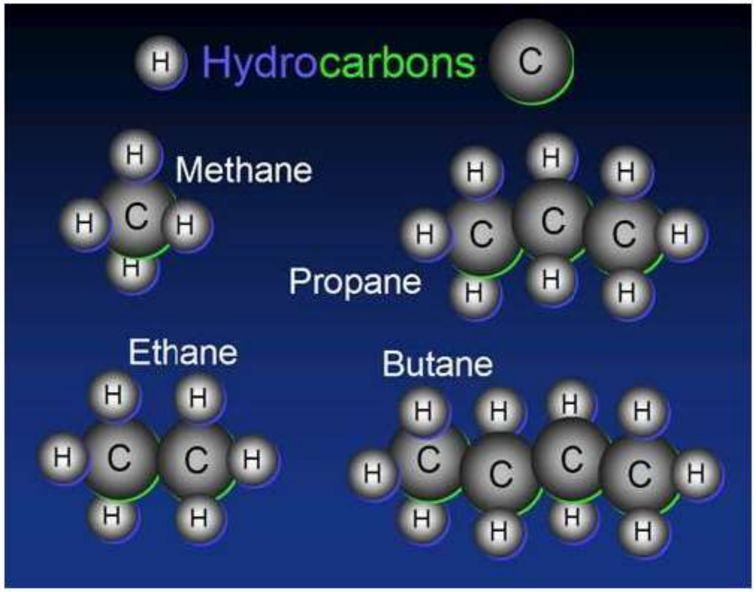
- Explaining the relationship between P, V and T.
- Boyles Law: P1V1 = P2V2
- Charles Law: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
- Equation of States:

  Ideal gases: PV = nRT

  Real gases: PV = znRT

Some related questions .....

- Are LPGs gaseous or liquids?
- Can NG (methane) be liquified? How?
- Why is NG transported through pipelinse in the gaseous state?
- What is the physical state of NG in the NGV tank? Why ?
- What about in the LNG tanker? Why? How?



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Are LPGs gaseous or liquid?

LPG exists in two different forms, liquid and gas (vapour).
The pressure and temperature at which it is stored determines which kind you have.
As a liquid, it is stored in a pressurised vessel.
It is typically used as a gas (vapour) but there are liquid applications, as well.

How Does LPG Work?

LPG is stored under pressure, as a liquid, in a gas bottle.
It turns back into gas vapour when you release some of the pressure in the gas bottle by turning on your gas appliance.
The LPG gas vapour is held in the top of the bottle and the liquid LPG at the bottom, as shown in the accompanying image.
Almost all of the uses for LPG involve the use of the gas vapour, not the liquefied gas.

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Can NG (methane) be liquified? How?

NG converted from gaseous to liquid form for ease of storage or transport. NG can be converted into liquefied natural gas (LNG), a process called **<u>liquefaction</u>**. LNG is natural gas that has been cooled to –260° F (–162° C), changing it from a gas into a liquid that is 1/600th of its original volume.

What about in LNG tanker? Why? How?

Why NG transported through pipeline in the gaseous state?

If in liquid form – temperature very low (-162^{o}C) so very difficult to maintain the pipe from freezing and other problem related with low temperature. Furthermore need to install extra equipment to convert back to gaseous from liquid form before sending the natural gas to consumer.

What is the physical state of NG in the NGV tank? Why?

NGV is either use CNG or LNG

If CNG – gaseous state ,
If LNG – liquid state, liquified natural gas,

Although vehicles can use natural gas as either a liquid or a gas, most vehicles use the **gaseous** form compressed to high pressures. LNG need extra equipment so gaseous form is preferred

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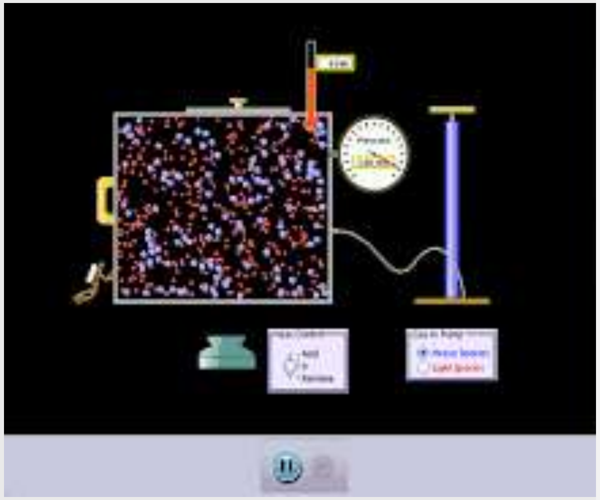
SOME COMMON TABLES OF PROPERTIES AND CHARACTERISTIC OF HYDROCARBONS & HYDROCARBON GASES



No.	Natural gas	LPG
1	Main H/C components: methane and ethane	Main H/C components : propane and butane
2	Gaseous form at atmopheric temp. and pressure	Liquid form at atmospheric temp. and at slightly above atmospheric pressure
3	Conversion from gas to liquid only through liquefaction/cooling process, not through compression	Conversion from gas to liquid either through compression or colling processes
4	CV ~ 38 MJ/m^3	CV ~ 100 MJ/m^3
5	SG ~ 0.65	SG ~ 1.85
6	Supplied to customer via pipeline	Supplied to customer via cylinder/tank
7	Flame temp. ~ 1930 ^oC	Flame temp. ~ 2000 ^oC
8	Flammability limit : ~ 5% - 15%	Flammability limit : ~ 2% - 10%

COMPARISON OF THE PROPERTIES OF TYPICAL GASES

Property	Units	NG	Commercial Propane	Butane/Air Mixtures
CV	MJ/m3	39.3	97.3	23.75
SG	air=1	0.58	1.5	1.19
Wobbe #	MJ/m3	51.64	79.4	21.79
Air Required	Vol air/Vol gas	9.75	23.8	4.89
Flammability Limits	% gas in air	5 to 15	2 to 10	1.6 to 7.75
Flame Speed	m/s	0.36	0.46	0.38
Ignition T	°C	704	530	500

Comparison of LPG and natural gas

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Gas components				
Methane	CH_4 (vol. %)	84.75	92.74	
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	(vol. %)	18.4	18.7	15.1
N_2	(m^3/m^3)	7.96	7.7	22.76
	(vol. %)	71.5	71.5	73.0
Net Wobbe index		10705	10713	18604

Properties of Paraffin Hydrocarbons[3,4]

Component	Methane	Ethane	Propane	iso-Butane	*n*-Butane	iso-Pentane	*n*-Pentane	*n*-Hexane	*n*-Heptane	*n*-Octane	*n*-Nonane	*n*-Decane
Molecular Weight	16.043	30.070	44.097	58.124	58.124	72.151	72.151	86.178	100.205	114.232	128.259	142.286
Boiling Point @ 101.3250 kPa (abs), K	111.63	184.57	231.08	261.34	272.66	300.99	309.21	341.89	371.57	398.82	423.97	447.31
Freezing Point @ 101.3250 kPa (abs), K	90.68	90.35	85.47	113.55	134.79	113.25	143.42	177.83	182.57	216.39	219.66	243.51
Vapor Pressure @ 313.15 K, kPa (abs)	(35 000.)	(6000.)	1341.	528.	377.	151.3	115.66	37.28	12.34	4.143	1.40	0.4732
Density of Liquid @ 288.15 K & 101.3250 kPa (abs)												
Relative density (water = 1)	(0.3)	0.3581	0.5083	0.5637	0.5847	0.6250	0.6316	0.6644	0.6886	0.7073	0.7224	0.7346
Absolute density, kg/m^3 (in vacuum)	(300.)	357.8	507.8	563.2	584.2	624.4	631.0	663.8	688.0	706.7	721.7	733.9
Apparent density, kg/m^3 (in air)	(300.)	356.6	506.7	562.1	583.1	623.3	629.9	662.7	686.9	705.6	720.6	732.8
Density of Gas @ 288.15 K & 101.3250 kPa (abs)												
Relative density (air = 1), ideal gas	0.5539	1.0382	1.5225	2.0068	2.0068	2.4911	2.4911	2.9753	3.4596	3.9439	4.4282	4.9125
Kilogram per cubic metre, kg/m^3, ideal gas	0.6784	1.2718	1.8650	2.4582	2.4582	3.0516	3.0516	3.6443	4.2373	4.8309	5.4259	6.0168
Volume @ 288.15 K & 101.3250 kPa (abs)												
Liquid, cm^3/mol	(50.)	84.04	86.84	103.2	99.49	115.6	114.3	129.8	145.6	161.6	177.7	193.9
Ratio, gas/(liquid in vacuum)	(442.)	281.3	272.3	229.1	237.6	204.6	206.8	182.1	162.4	146.3	133.0	122.0
Critical Conditions												
Temperature, K	190.55	305.43	369.82	408.13	425.16	460.39	469.6	507.4	540.2	568.76	594.56	617.4
Pressure, kPa (abs)	4604.	4880.	4249.	3648.	3797.	3381.	3369.	3012	2736.	2486.	2288.	2099.
Gross Calorific Value, Combustion @ 288.15 K & Constant Pressure												
Megajoule per kilogram, MJ/kg, liquid	–	51.586	50.008	49.044	49.158	48.579	48.667	48.344	48.104	47.919	47.783	47.670
Megajoule per kilogram, MJ/kg, ideal gas	55.563	51.920	50.387	49.396	49.540	48.931	49.041	48.722	48.482	48.290	48.137	48.043
Megajoule per cubic metre, MJ/m^3, ideal gas	37.694	66.032	93.972	121.426	121.779	149.319	149.654	177.556	205.431	233.286	261.189	289.066
Megajoule per cubic metre, MJ/m^3, liquid	–	18458.	25394.	27621.	28718.	30333.	30709.	32091.	33095	33865.	34485.	34985.
Volume air to burn one volume gas, ideal gas	9.54	16.70	23.86	31.02	31.02	38.18	38.18	45.34	52.50	59.65	66.81	73.97
Flammability Limits @ 310.93 K & 101.3250 kPa (abs)												
Lower, volume % in air	5.0	2.9	2.0	1.8	1.5	1.3	1.4	1.1	1.0	0.8	0.7	0.7
Upper, volume % in air	15.0	13.0	9.5	8.5	9.0	8.0	8.3	7.7	7.0	6.5	5.6	5.4
Heat of Vaporization @ 101.3250 kPa (abs)												
kJ/kg @ boiling point	509.86	489.36	425.73	366.40	385.26	342.20	357.22	334.81	316.33	301.26	288.82	276.06
Specific Heat @ 288.15 K & 101.3250 kPa (abs)												
C_p gas, kJ/(kg·K), ideal gas	2.204	1.706	1.625	1.616	1.652	1.600	1.622	1.613	1.606	1.601	1.598	1.595
C_v gas, kJ/(kg·K), ideal gas	1.686	1.429	1.436	1.473	1.509	1.485	1.507	1.517	1.523	1.528	1.533	1.537
$K = C_p/C_v$, ideal gas	1.307	1.194	1.132	1.097	1.095	1.077	1.076	1.063	1.054	1.048	1.042	1.038
C_p liquid, kJ/(kg·K)	–	3.807	2.476	2.366	2.366	2.239	2.292	2.231	2.209	2.191	2.184	2.179

Units of Measurement

- The standard unit of volume used in natural gas measurement is a **cubic feet** corrected to a standard pressure and temperature (scf). Large volumes of natural gas are usually expressed in units of one thousand cubic feet (Mcf)
- When a gas sample is analyzed, however, the composition is usually expressed in mole percent –the percent (by number) of moles of the particular substance out of the total molecules of the gas. This is roughly equivalent to volume percent. For example, the molecular weight of water is 18, so a mole of water is 18 grams and contain 6.022 x 10^{-23} molecules.
- Moles are often used in chemistry because they make it easier to keep track of quantities of substances involved in chemical reactions.
- One mole of oxygen will react with 2 moles of hydrogen to form one mole of water
- However, there would be an excess of hydrogen if one gram of oxygen were reacted with 2 grams of hydrogen.

Physical Properties of Gases

Among the important physical properties NG and LPGs that are commonly measured in oil and gas operations:

- Density/Specific gravity
- Vapor Pressure
- Boiling point
- Dew Points
- Odor
- Energy content/ Calorific Value/Heating Value
- Toxicity
- Flammability (UEL/LFL)
- Flame Speed

Specific Gravity (SG)

- SG of a fuel is the ratio between the gas fuel density and the dry air density of at the same condition (P and T)

$$SG = \frac{\rho_{fuel}}{\rho_{air}}$$

- In the gas industry, standard conditions of P & T are 101.3 kPa and 15°C
- SG depends very much on its gas mixture composition
- SG of a gas (commonly called `WEIGHT') determines whether gas will rise or fall when released in the air.
- SG has two practical importance
  - Effect on the flow of gases through orifices or pipe
  - Rating of burners – burner conversion

<u>Example:</u> Relative density or SG of NG.

$$SG = \frac{0.799\ kg/sm3}{1.2248\ kg/sm3} = 0.652$$

SG of multi-components fuel can be calculated as follows

- $$SG = \sum_{i=1}^{i=n} y_i SG_i$$
- where y_i = mole fraction (vol. %) of fuel component i
  SG_i = specific gravity of fuel component i

Fuel	Relative (mol) weight	Specific weight at 0°C & atm. (kg/m³)	Specific gravity (air=1)
Hydrogen (H_2)	2.020	0.0898	0.0695
Methane (CH_4)	16.04	0.7167	0.5540
Ethane (C_2H_6)	30.07	1.3567	1.0494
Propane (C_3H_8)	44.10	2.0200	1.5625
Butane (C_4H_{10})	58.12	2.5985	2.085
Carbon monoxide (CO)	28.01	1.2501	0.9670
Carbon dioxide (CO_2)	44.01	1.9768	1.5291
Oxygen (O_2)	32.00	1.4289	1.1053
Nitrogen (N_2)	28.02	1.2507	0.9674
Water vapour (H_2O)	18.02	0.8040	0.6219
Air	28.97	1.2928	1.000

Tutorial 1

Item		Natural Gas Before '95	Natural Gas After 95'	LPG
Gas components				
Methane	CH_4 (vol. %)	84.75	92.74	
Ethane	C_2H_6 (vol. %)	10.41	4.07	
Propane	C_3H_8 (vol. %)	0.98	0.77	30
Butane	C_4H_{10} (vol.%)	0.11	0.14	70
Nitrogen	N_2 (vol. %)	0.39	0.45	
Carbon dioxide	CO_2 (vol. %)	3.36	1.83	

Calculate the specific gravity of natural gas and LPG compositions as shown above.

Example calculation of SG for NG before 1995

Symbol	Composition (vol%) (A)	Specific Gravity (B)	(A) X (B) / 100
CH_4	84.75	0.555	0.4704
C_2H_6	10.41	1.048	0.1091
C_3H_8	0.98	1.554	0.0152
$I\text{-}C_4H_{10}$	0.07	2.085	0.0015
$N\text{-}C_4H_{10}$	0.04	2.085	0.0008
N_2	0.39	0.9674	0.0038
CO_2	3.36	1.5291	0.0514
TOTAL	100.0	-	**0.6522**

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Lets try to calculate SG for natural gas after 1995

Symbol	Composition (vol%) (A)	Specific Gravity (B)	$\frac{(A) \times (B)}{100}$
CH_4		0.555	
C_2H_6		1.048	
C_3H_8		1.554	
$I\text{-}C_4H_{10}$		2.085	
$N\text{-}C_4H_{10}$		2.085	
N_2		0.9674	
CO_2		1.5291	
TOTAL		-	

Lets try to calculate SG for natural gas after 1995

Symbol	Composition (vol%) (A)	Specifik graviti (B)	(A) X (B) / 100
C_3H_8	30.00	1.554	0.4662
C_4H_{10}	70.00	2.085	1.4595
Total	100.00	-	**1.9257**

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Boiling Point

The temperature at which the vapour pressure of a liquid equals the atmospheric pressure

Dew Points

Temperature at which hydrocarbons start to condense from agas stream. This is important in gas production and transmission because condensation in a natural gas line will lower the capacity of the line to carry gas. Consequently, there will be problems with compressors, dehydrators and other processing equipment. More importantly liquids in a gas line make it impossible to accurately measure the gas. The dew point also allows the heavier gases to be liquefied by processing. They are generally more valuable as liquids than gas.

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Odour

Odorizing is important in gas processing and transportation as a relatively inexpensive way of determining the location of leaks. Unles it contains high concentrations of hydrogen sulfide or other contaminants, natural gas is normally odorless and nontoxic when it comes out of the ground. Nontoxic odorants, such as mercaptans are added during processing to make it detectable by sense of smell.

Heating Value

- The Btu or British Thermal Unit ia a measure of the energy produced by burning natural gas
- A Btu is equal to the amountn of heat required to raise the temperature of one pound of water one degree Fahrenheit at 62^{o}F
- The Btu may be expressed as dry, wet or as delivered. The dry Btu calculation assumes that there is no water vapor in the gas
- As might be expected, teh wet Btu is calculated on the assumption that the gas is saturated with water vapor at standard conditions (60^{o}F and atmospheric pressure)

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Heating Value

- Hence, the wet Btu is less than the dry Btu. The gas delivered or actual Btu is calculated by accounting for the actual amount of water in the gas based on delivery conditions
- The Btu factors of the individual components in natural gas, increase with the number of carbon atoms. The table in Figure 1 illustrates the Btu of the most common components in natural gas
- Water vapor, though it does not burn, has a heating value as defined by this industry. Water vapor has a heating value of 50.4 Btu per standard cubic foot.

Table – HC Energy Content

Carbon Number	Name	Btu @14.696 psia and 60ºF
1	Methane	1010.0
2	Ethane	1769.7
3	Propane	2516.1
4	Iso-butane	3251.9
5	N-butane	3262.3
6	Iso-pentane	4000.9
7	N-pentane	4008.9
8	Hexane	4755.9

Gross Heat of Combustion/ Gross CV/ HHV

The amount of heat released (including the heat of condensation of water vapor) when <u>stoichiometric</u> air/gas mixture is completely burned to yield specified products, with both reactants and products at 25^{o}C and 1 atm.

CV of a gas fuel is determined/measured by Gas chromatography or Boy's Calorimeter. CV's for pure/single component gas fuel are usually tabulated along with other properties.

Gross CV can also be determined from tabulated heat of formation data as shown below:

$$CH_4(vap) + 2O_2(vap) \rightarrow CO_2(vap) + 2H_2O(\ liq)$$

25^{o}C 25^{o}C

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Gross

By condensing the water vapor, we extract /recover more heat (the latent heat of vaporization of water) from the combustion products.

So, if the water in the combustion products is in liquid form,

$$CH_4 + 2O_2 + 7.55N_2 \rightarrow 2H_2O\ (l) + CO_2\ (g) + 7.55N_2(g)$$

ΔH^o_{comb} is gross heat of combustion and the calorific value is gross calorific value.

Gross CV, HHV

$CH_4(vap) + 2O_2(vap) \rightarrow CO_2(vap) + 2H_2O(liq)$

25°C 25°C

Gross CV

$= \Sigma n\Delta H_f$ product $- \Sigma n\Delta H_f$ reactant

$= 1(\Delta H_f\ CO_2) + 2(\Delta H_f\ H_2O) - 1(\Delta H_f\ CH_4) - 2(\Delta H_f\ O_2)$

$= 1mol\ (-393.5KJ/mol) + 2(-285.84) - 1(-74.85) - 2(0)$

$= -890.3\ KJ/mol$

Net

Net Calorific Value

If the water in the combustion products is in gas form,

$$CH_4 + 2O_2 + 7.55N_2 \rightarrow 2H_2O\ (g) + CO_2\ (g) + 7.55N_2(g)$$

ΔH^o_{comb} is net heat of combustion and the calorific value is net calorific value.

Net CV, LHV

CH_4(vap) + $2O_2$(vap) → CO_2(vap) + $2H_2O$(vap)

25^{o}C 25^{o}C

Net CV

= $\Sigma n\Delta H_f$ product - $\Sigma n\Delta H_f$ reactant

= 1(ΔH_f CO_2) + 2(ΔH_f H_2O) - 1(ΔH_f CH_4) - 2(ΔH_f O_2)

= 1mol (-393.5KJ/mol) + 2(-241.83) - 1(-74.85) - 2(0)

= -802.31 KJ/mol

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$$CV\ gross = CV_{net} + \Delta H_{vap}\ H_2O$$

For natural gas, Net CV is approximately equal to 90% of the gross CV.

$$CV_{net} = 0.9CV_{gross}$$

Typical CV for natural gas:

Net CV	34.9 MJ/Sm^3	919.0 Btu/Sft^3
Gross CV	38.65 MJ/Sm^3	1018.0 Btu/Sft^3

CV will change if the gas composition change. Customers buy the **energy** of the gas, not the volume. However the amount of gas sold is measured in term of volume not energy (domestic and commercials and sometimes industrial). Gross CV is normally used by gas company to charge their customers.

Heat of Combustion

Standard heat of combustion $\Delta\hat{H}_c^o$ of a combustible is the heat of the reaction of that combustible with oxygen to yield specific products (i.e. CO_2 and H_2O), with both reactants and products at reference state 25°C and 1 atm.

$$\Delta H_c^o = \sum_{products} v_i \left(\Delta H_f^o\right)_i - \sum_{reactants} v_i \left(\Delta H_f^o\right)_i$$

Tutorial 2

Calculate the heat of combustion of methane (CH_4) assuming

i) liquid water as a combustion product

ii) vapour water as a combustion product

Table B-6 Enthalpy of Formation and Enthalpy of Vaporization

25 °C (77 °F), 1 atm

Substance	Formula	$\bar{h}^{\circ}_{f}$ kJ/kmol	$\bar{h}_{fg}$ kJ/kmol	$\bar{h}^{\circ}_{f}$ Btu/lbmol	$\bar{h}_{fg}$ Btu/lbmol
Carbon	$C(s)$	0		0	
Hydrogen	$H_2(g)$	0		0	
Nitrogen	$N_2(g)$	0		0	
Oxygen	$O_2(g)$	0		0	
Carbon monoxide	$CO(g)$	−110 530		−47,540	
Carbon dioxide	$CO_2(g)$	−393 520		−169,300	
Water	$H_2O(g)$	−241 820		−104,040	
Water	$H_2O(l)$	−285 830	44 010	−122,970	
Hydrogen peroxide	$H_2O_2(g)$	−136 310	61 090	−58,640	26,260
Ammonia	$NH_3(g)$	−46 190		−19,750	
Oxygen	$O(g)$	249 170		+107,210	
Hydrogen	$H(g)$	218 000		+93,780	
Nitrogen	$N(g)$	472 680		+203,340	
Hydroxyl	$OH(g)$	39 040		+16,790	
Methane	$CH_4(g)$	−74 850		−32,210	
Acetylene (Ethyne)	$C_2H_2(g)$	226 730		+97,540	
Ethylene (Ethene)	$C_2H_4(g)$	52 280		+22,490	
Ethane	$C_2H_6(g)$	−84 680		−36,420	
Propylene (Propene)	$C_3H_6(g)$	20 410		+8,790	
Propane	$C_3H_8(g)$	−103 850	15 060	−44,680	6,480
n-Butane	$C_4H_{10}(g)$	−126 150	21 060	−54,270	9,060
n-Pentane	$C_5H_{12}(g)$	−146 440	31 410		
n-Octane	$C_8H_{18}(g)$	−208 450	41 460	−89,680	17,835
Benzene	$C_6H_6(g)$	82 930	33 830	+35,680	14,550
Methyl alcohol	$CH_3OH(g)$	−200 890	37 900	−86,540	16,090
Ethyl alcohol	$C_2H_5OH(g)$	−235 310	42 340	−101,230	18,220

SOURCES: JANAF Thermochemical Tables, NSRDS-NBS-37, 1971; *Selected Values of Chemical Thermodynamic Properties*, NBS Technical Note 270-3, 1968; and API Res. Project 44, Carnegie Press, Carnegie Institute of Technology, Pittsburgh, 1953.

Table B-7 Enthalpy of Combustion and Enthalpy of Vaporization

25 °C (77 °F), 1 atm

Substance	Formula	−HHV kJ/kmol	$\bar{h}_{fg}$ kJ/kmol	−HHV Btu/lbmol	$\bar{h}_{fg}$ Btu/lbmol
Hydrogen	$H_2(g)$	−285 840		−122,970	
Carbon	$C(s)$	−393 520		−169,290	
Carbon monoxide	$CO(g)$	−282 990		−121,750	
Methane	$CH_4(g)$	−890 360		−383,040	
Acetylene	$C_2H_2(g)$	−1 299 600		−559,120	
Ethylene	$C_2H_4(g)$	−1 410 970		−607,010	
Ethane	$C_2H_6(g)$	−1 559 900		−671,080	
Propylene	$C_3H_6(g)$	−2 058 500		−885,580	
Propane	$C_3H_8(g)$	−2 220 000	15 060	−955,070	6,480
n-Butane	$C_4H_{10}(g)$	−2 877 100	21 060	−1,237,800	9,060
n-Pentane	$C_5H_{12}(g)$	−3 536 100	26 410	−1,521,300	11,360
n-Hexane	$C_6H_{14}(g)$	−4 194 800	31 530	−1,804,600	13,560
n-Heptane	$C_7H_{16}(g)$	−4 853 500	36 520	−2,088,000	15,710
n-Octane	$C_8H_{18}(g)$	−5 512 200	41 460	−2,371,400	17,835
Benzene	$C_6H_6(g)$	−3 301 500	33 830	−1,420,300	14,550
Toluene	$C_7H_8(g)$	−3 947 900	39 920	−1,698,400	17,180
Methyl alcohol	$CH_3OH(g)$	−764 540	37 900	−328,700	16,090
Ethyl alcohol	$C_2H_5OH(g)$	−1 409 300	42 340	−606,280	18,220

Note: Water appears as a liquid in the products of combustion.

SOURCE: Kenneth Wark, *Thermodynamics*, 3d ed., McGraw-Hill, New York, 1981, pp. 834–835, Table A-23M.

Calorific Value (CV)

- Also known as heating value (HV) - Quantity of heat release from combustion of unit weight or volume of fuel (MJ/kg or Kcal/kg or Kcal/ m^3 or MJ/m^3)
  - Higher or **gross CV** (HCV or HHV) – when liquid water as a combustion product – taking account the presence of water vapor in flue gases
  - Lower or **net CV** (LCV or LHV) – when vapour water as a combustion product - the difference between higher CV and the heat absorbed (latent heat) by water in having its phase changing to vapour
- Negative of standard heat of combustion, … hence CV value is always positive
- The more carbon and hydrogen atoms in each molecule of a fuel the higher will be its CV or heating value.
- The larger the amount of inert matters, such as nitrogen and carbon dioxide, or water content, present in a fuel the lower the CV will be.

Calorific Value (CV)

- If latent heat corresponding to 25°C saturation temp. = 44010 kJ/kmol, is assumed

  - Net CV = gross CV – latent heat of water
  - LCV = (HCV - y_{H2O}.44010) kJ/kmol, where y_{H2O} = mol fraction of water vapor in flue gases

- From tutorial 2

$HCV_{methane}$ = **890, 330** kJ/kmol
$LCV_{methane}$ = $HCV_{methane}$ - vDH_{vap}
$LCV_{methane}$ = 890, 330 – 2(44010) kJ/kmol
= **802,310** kJ/kmol

- Net CV is aproximately 90% of gross CV.

  Customers buy the energy of the gas, not the volume. However, the amount of gas sold is measured in term of volume , not energy. Gross CV or HCV is normally used by gas company to charge their customer

CV for several gas

Component		Caloric value per unit volume				Per unit weight	
		Gross	Net	Gross	Net	Gross	Net
Name	Symbol	Kcal/Nm^3 Btu/Nm^3		Kcal/Sm^3 Btu/Sm^3		Kcal/kg Btu/kg	
Hydrogen	H_2	3053 12115	2573 10210	2893 11480	2439 9679	33998 134913	28653 113702
Carbon Monoxide	CO	2016 11968	3016 11968	2859 11345	2859 11345	2412 9575	2413 9575
Methane	CH_4	9537 3784	8574 3402	9041 35877	8128 32254	13307 52806	11963 47472
Ethylene	C_2H_4	15179 60234	14211 56392	14389 57099	13471 53456	12005 47639	11239 44599
Ethane	C_2H_6	16834 66802	15379 61028	15958 63325	14578 57849	12408 49238	11336 44984
Propylene	C_2H_6	22385 88829	20917 83004	21220 84206	19828 78683	11690 46389	10923 43345
Propane	C_3H_8	24229 96147	22267 88361	22968 91143	21108 83762	11995 47599	11023 43742
Butylene	C_4H_8	29110 115516	27190 107897	27595 10950	25775 102282	11602 46040	10837 43004
N-Butane	C_4H_{10}	32022 127071	29520 117143	30355 120456	27983 111044	12323 48901	11360 45079
I-Butane	C_4H_{10}	31781 126115	29289 116226	30127 119552	27764 110175	12231 48536	11272 44730

Heat of Combustion, ΔH_c

The heat of the reaction of that combustible with oxygen to yield specific products (i.e. CO_2 and H_2O), with both reactants and products at reference state 25°C and 1 atm.

$CV = -\Delta H_c$

↓

Hence CV is always positive

Tutorial 3

Natural gas contains 85% methane and 15% ethane by volume, calculate the gross heating value of this fuel mixture in KJ/Sm^3 and KJ/Kg from the standard heat of combustion of methane and ethane.

$$CH_4(g) + 2O_2(g) --> CO_2(g) + 2H_2O(l); \Delta\hat{H}_c^o = -890.3 kJ/mol$$

$$C_2H_6(g) + \frac{7}{2}O_2(g) --> 2CO_2(g) + 3H_2O(l); \Delta\hat{H}_c^o = -1559.9 kJ/mol$$

- $HCV_{mix} = \Sigma\, y_i\, HCV_i$
- $AMWmix = \Sigma\, y_i\, MW_i$ (g/mol, kJ/kmol)

Molecular Weight (MW)

The sum of the atomic weight of the atom that constitute a molecule.

Example:

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

$[3(12.01)+ 8(1.008)] + 5[2x16] \rightarrow 3[12.01 + 2x16] + 4[2x1.008 + 1x16]$

$44.094 + 5 (32) \rightarrow 3(44.01) + 4 (18.016)$

$204.094 \rightarrow 204.094$

Unit of molecular weight: (mass/mole)

Example: H_2O: 18.016 g/mol or kg/kmol or lbm/lb-mole

Vapour Pressure

If T and P correspond to a point on the vaporization curve on PT diagram of a pure substance, then:

P is the vapor pressure of the substance at temperature T

T is the boiling point of the substance at pressure P

We can use Antoine equation, Cox Chart, Thermodynamic Table/Diagram to determine the vapor pressure of pure substance.

Flammability Limit

A range of fuel and air proportion in which combustion can be self-sustaining is known as flammability limits - These limits have limiting lean (lower limit) and limiting rich (upper limit)

Fuel	Lower limit		Upper limit	
	Vol. %	Air/Gas ratio	Vol. %	Air/Gas ratio
Hydrogen (H_2)	4.0	10.1	75.6	0.14
Methane (CH_4)	5.0	2.0	15.0	0.60
Ethane (C_2H_6)	3.0	1.9	12.5	0.42
Propane (C_3H_8)	2.1	2.0	9.5	0.4
Butane (n-C_4H_{10})	1.9	1.7	8.5	0.35
Natural gas	4.3	2.0	14.5	0.54

Flammability Limits

A range of percentage (by volume) of gas in air/gas mixtures within which the mixture can be ignited.

Example:

NG	: 5% to 15%
Propane	: 2% to 10%
H_2	: 4% to 75%

Flammability Limits

- Combustion will take place and be self-sustaining only if fuel and air are mixed within a certain range of mixture proportion

- A range of fuel and air proportion in which combustion can be self-sustaining is known as flammability limits - These limits have limiting lean (lower limit) and rich (upper limit)

- A premixed fuel-air mixture will only burn as long as the fuel concentration is between the upper and lower flammability limits,i.e. **UFL** and **LFL**

Flammability Limit

Fuel	Lower limit		Upper limit	
	Vol. %	Air/Gas ratio	Vol. %	Air/Gas ratio
Hydrogen (H_2)	4.0	10.1	75.6	0.14
Methane (CH_4)	5.0	2.0	15.0	0.60
Ethane (C_2H_6)	3.0	1.9	12.5	0.42
Propane (C_3H_8)	2.1	2.0	9.5	0.4
Butane (n-C_4H_{10})	1.9	1.7	8.5	0.35
Natural gas	4.3	2.0	14.5	0.54

	LFL	UFL
$CH_4 \longleftrightarrow$	5%	15%
$C_3H_8 \longleftrightarrow$	2.1%	9.5%

Burn only in this range with ignition depend on T & P

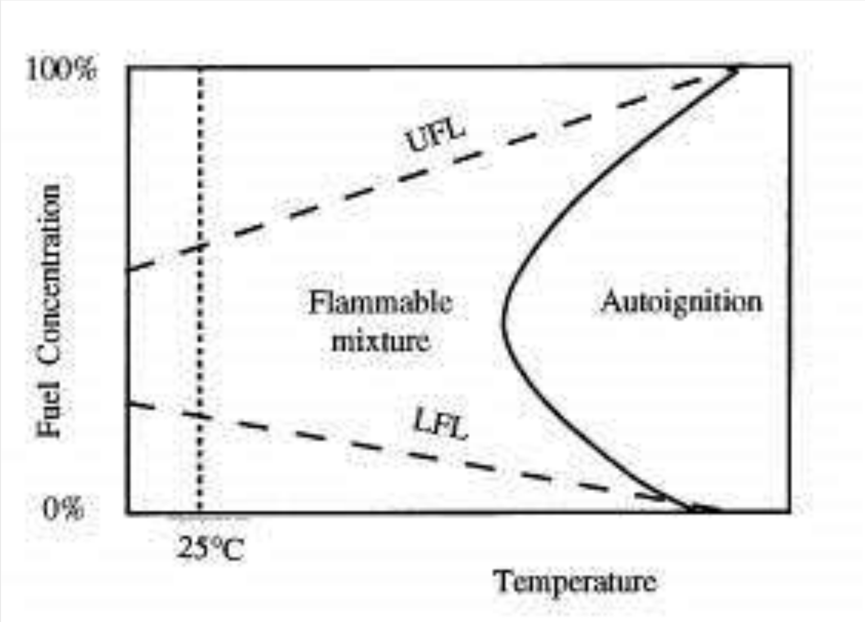
Flammability Limit

Flammability limits for fuel mixtures may be calculated by Le Chatelier's law:

$$LFL_{Mix} = \frac{100}{C_1/LFL_1 + C_2/LFL_2 + \cdots + C_i/LFL_i}$$

where C_1, C_2 ....C_i [vol.%] is the proportion of each gas in the fuel mixture without air.

Flammability Limit



flammability range is widen when temperature is increased

Flammability Limit

Effect of oxidant (O_2)

Expand the flammable range by increasing the upper limit

	Inflammability limit, % gas in the mixture			
Gases	**In Air**		**In oxygen**	
	Lower	Upper	Lower	Upper
Ethylene	3.1	32.0	3.0	80.0
Methane	5.3	15.0	5.1	61.0
Ethane	3.0	12.5	3.0	66.0
Hydrogen	4.0	75.0	4.0	94.0
Carbon monoxide	12.5	74.0	15.5	94.0

Flammability Limit

Effect on diluent (CO_2, N_2)

Narrow down the flammability limits by increasing the lower limit

Flammability limit of combustibles containing diluents can be represented as below;

$$FL_{mix,dil} = FL_{mix}\left(\frac{100}{100 - y_{dil}}\right)$$

$FL_{mix,\ dil}$ = vol. % flammability limit (lower or upper) of the combustibles containing diluents in air

FL_{mix} = vol. % flammability limit (lower or upper) of the pure combustibles in air

Y_{dil} = vol.% of diluents in the fuel mixture

Explosive Limits

- When the combustion of the fuel is not controlled within the confines of the burner system, the limits of flammability can be called the **Explosive Limits**.

- The explosive limits of NG are approximately

  LEL = 4%

  UEL = 14%

Portable Explosion Meters

- Detect the LEL of fuel gas
- Eg. **M40 Multi Gas Monitor**
- Principle of operations of various explosion meters is based on the principle of catalytic combustion. Where a filament consists of catalytic material will initiate the combustion of the mixture at low temperature. This causes changes in its electrical resistance which wil be detected by the meter.
- Reading less than 100% indicates sample is below the LEL.

Flame speed

- Flame velocity as it propagates in the opposite direction of air/gas mixture

- The speed at which the mixture is coming out has to be adjusted so that the flame will stay on the tip of the burner

- Typical flame speeds are:

NG : 0.36 m/s
Butane : 0.38 m/s

Fuel	Max. flame speed (cm/sec)	Air/gas Ratio	Vol. % fuel in mixture
Hydrogen (H_2)	282	0.58	42
Methane (CH_4)	39.2	0.90	10.5
Ethane (C_2H_6)	42.6	0.90	6.2
Propane (C_3H_8)	45.5	0.96	4.2
n-Butane (n-C_4H_{10})	37.5	1.0	3.1
i-Butane (i-C_4H_{10})	37.5	1.0	3.1
Natural gas	39	0.9	9

Flame speed

For any gaseous mixture the flame speed can be approximated by the following formula:

$$S = \frac{aS_a + bS_b + cS_c + ...}{a + b + c + ...}$$

where

S - flame velocity of the mixture

a, b, c - % vol. composition of constituent combustible gases

S_a, S_b, S_c - flame velocity of constituent gases

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Tutorial 4

Calculate the maximum flame velocity of a gas mixture containing (by vol.)

85% CH_4
10.4% C_2H_6
0.98% C_3H_8
0.11% C_4H_{10}
0.39% N_2
3.12% CO_2

$$S = \frac{aS_a + bS_b + cS_c + \ldots\ldots}{a + b + c + \ldots\ldots}$$

Flame Velocity

- The rate of flame surface propagation into the un-burnt combustible mixture to ensure continuous and successful flame propagation

- Also known as burning velocity or combustion velocity.

- Flame velocity depends on the fuel-air mixture composition and attains maximum for mixture slightly richer in fuel content than the stoichiometric compositions and rises if the initial temperature is increased or the pressure of the system is decreased

Ignition Temperatures

The temperature at which the rate of oxidation increase abruptly (burst into flame).

e.g.:

NG	: 704^{o}C
Commercial Propane	: 530^{o}C

Ignition Temperature

An amount of energy externally supplied to initiate combustion is called ignition energy and its corresponding temperature is known as ignition temperature. The minimum ignition energy is a measure of required energy for a localised ignition source, like a spark, to successfully ignite a fuel-oxidiser mixture.

Fuel	Min. Ignition temperature (°C)
Hydrogen (H_2)	560
Methane (CH_4)	595
Ethane (C_2H_6)	515
Propane (C_3H_8)	470
n-Butane (n-C_4H_{10})	460
i-Butane (i-C_4H_{10})	460
LPG	~ 450-470
Natural gas	~ 630-730

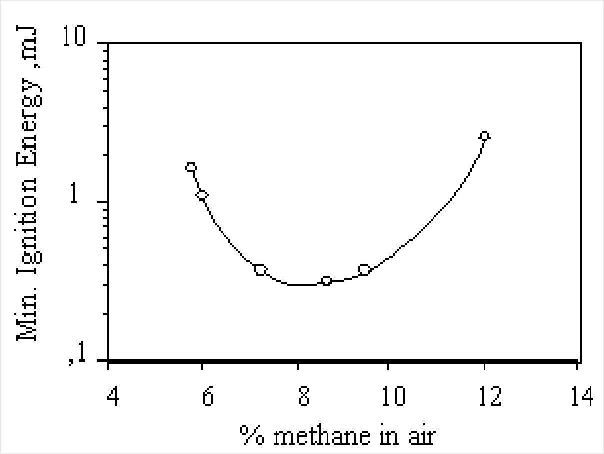
(Source : Physical property data)

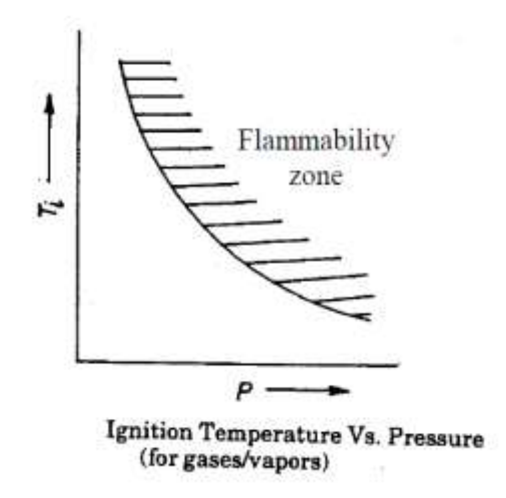
→ Lowest Tempt for combustion to initiate

Ignition Temperature

- The ignition energy depends on the fuel concentration
  - For most combustible fuels the minimum ignition energy is between 0.1 and 0.3 mJ in normal ambient air.

- Minimum ignition temperature also decreases with increasing pressure





Flame Temperature

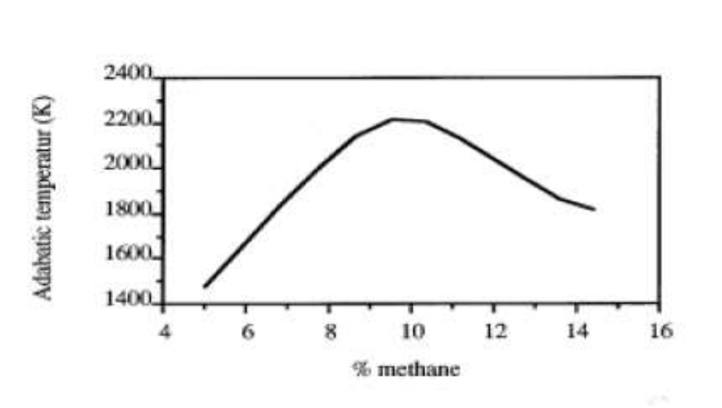
The temperature of the flame corresponds to heat generated during combustion process

Flame temperature of fuel depends on

- Calorific value
- Volume and specific heat of total gaseous products
- Losses by radiation
- Latent heat in water vapour in the combustion products
- Endothermic dissociation of gaseous molecules, mainly CO_2 and H_2O

Flame Temperature

- The flame temperature is strongly a function of fuel concentration
- The maximum adiabatic flame temperature occurs close to the stoichiometric composition (i.e. 9.5% methane in air)
- Adiabatic flame temperature of methane combustion for initial conditions 1 atm. and 25°C.



COMPARISON OF THE PROPERTIES OF TYPICAL GASES

Property	Units	NG	Commercial Propane	Butane/Air Mixtures
CV	MJ/m3	39.3	97.3	23.75
SG	air=1	0.58	1.5	1.19
Wobbe #	MJ/m3	51.64	79.4	21.79
Air Required	Vol air/Vol gas	9.75	23.8	4.89
Flammability Limits	% gas in air	5 to 15	2 to 10	1.6 to 7.75
Flame Speed	m/s	0.36	0.46	0.38
Ignition T	°C	704	530	500

Question?

THE END

Thank you for the attention!!

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Associated Gas

Associated gas, is a form of natural gas which is found with deposits of petroleum, either dissolved in the oil or as a free "gas cap" above the oil in the reservoir.[1][2] Historically, this type of gas was released as a waste product from the petroleum extraction industry. It may be a stranded gas reserve due to the remote location of the oil field, either at sea or on land, this gas is simply burnt off in gas flares. When this occurs the gas is referred to as **flare gas**

Associated Gas

Associated gas is gas produced as a byproduct of the production of crude oil. Associated gas reserves are typically developed for the production of crude oil, which pays for the field development costs. The reserves typically produce at peak levels for a few years and then decline.

Associated gas is generally regarded as an undesirable byproduct, which is either reinjected, flared, or vented. According to 2010 statistics from the US Energy Information Administration,[1] worldwide approximately 4.3 Tcf/yr of gas was flared or vented, and an additional 17.1 Tcf/yr of gas was reinjected. The need to produce oil and dispose of natural gas (as is the case with associated gas) requires unique approaches in the field-development plans.

Sweet or Sour Gas

Sweet Gas is natural gas that is found as a hydrogen sulfide. The gas may also not contain any quantities of carbon dioxide. The composition of the gas determines whether it is sweet or sour. Sweet Gas in its purest form can be used with very little refining. It is not corrosive in nature; hence it is relatively easy to use as compared to sour gas. When natural gas contains high levels of acidic gases such as hydrogen sulfide, it is referred to as acid gas. If it contains high levels of sulfur, it is referred as sour gas.

LPGases

Liquefied petroleum gas or **liquid petroleum gas** (**LPG** or **LP gas**), also referred to as simply propane or butane, are flammable mixtures of hydrocarbon gases used as fuel in heating appliances, cooking equipment, and vehicles.

Industrial Gases

Industrial gases are gaseous materials that are manufactured for use in Industry. The principal gases provided are nitrogen, oxygen, carbon dioxide, argon, hydrogen, helium and acetylene; although a huge variety of gases and mixtures are available in gas cylinders. The industry producing these gases is known as the industrial gases industry, which is seen as also encompassing the supply of equipment and technology to produce and use the gases.[1] Their production is a part of the wider chemical Industry (where industrial gases are often seen as "speciality chemicals").

Industrial gases are used in a wide range of industries, which include oil and gas, petrochemicals, chemicals, power, mining, steelmaking, metals, environmental protection, medicine, pharmaceuticals, biotechnology, food,water, fertilizers, nuclea r power, electronics and aerospace. Industrial gas is sold to other industrial enterprises; typically comprising large orders to corporate industrial clients, covering a size range from building a process facility or pipeline down to cylinder gas supply.

NGV – Natural gas vehicle
CNG – Compressed NG
LNG – Liquified NG

A **natural gas vehicle** (**NGV**) is an alternative fuel vehicle that uses compressed natural gas (CNG) or liquefied natural gas (LNG) as a cleaner alternative to other fossil fuels.

Compressed natural gas (**CNG**) (methane stored at high pressure) can be used in place of gasoline (petrol), Diesel fuel and propane/LPG

Liquefied natural gas (**LNG**) is natural gas (predominantly methane, CH_4, with some mixture of ethane C_2H_{6f}) that has been converted to liquid form for ease of storage or transport. It takes up about 1/600th the volume of natural gas in the gaseous state

Retail price of automotive fuels (2004/2016)

FUEL	PRICE, RM/LITRE
NGV	0.5~0.6/1.05
Petrol (Ron95)	1.42/1.75
Diesel	0.83/1.70

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Town Gas & Manufactured Gas

Coal gas is a flammable gaseous fuel made from coal and supplied to the user via a piped distribution system. **Town gas** is a more general term referring to manufactured gaseous fuels produced for sale to consumers and municipalities.

Manufactured gas – also known as artificial gas. Before NG was produced, company manufactured gas from coal, or coal and oil mixture from petroleum.

Flue gas

Flue gas is the gas exiting to the atmosphere via a flue, which is a pipe or channel for conveying exhaust gases from a fireplace, oven, furnace, boiler or steam generator. Quite often, the flue gas refers to the combustion exhaust gas produced at power plants. Its composition depends on what is being burned, but it will usually consist of mostly nitrogen (typically more than two-thirds) derived from the combustion of air, carbon dioxide (CO_2), and water vapor as well as excess oxygen (also derived from the combustion air). It further contains a small percentage of a number of pollutants, such as particulate matter (like soot), carbon monoxide, nitrogen oxides, and sulfur oxides

Biogas

Biogas typically refers to a mixture of different gases produced by the breakdown of organic matter in the absence of oxygen. Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste. Biogas is a renewable energy source and in many cases exerts a very small carbon footprint.

GPP – Gas Processing Plant

Natural-gas processing is a complex industrial process designed to clean raw natural gas by separating impurities and various non-methane hydrocarbons and fluids to produce what is known as *pipeline quality* dry natural gas

Natural-gas processing plants purify raw natural gas by removing common contaminants such as water, carbon dioxide (CO_2) and hydrogen sulfide (H_2S). Some of the substances which contaminate natural gas have economic value and are further processed or sold

Dehydration

Hydrates- crystalline substances formed by associated molecules of hydrogen and water and having a crystalline structure. Natural gas hydrates look like wet pressed snow turning into ice. Having accumulated in the gas pipeline, they can choke or completely block the pipe and cause damage to the system's operating conditions.

When large gas volumes are transported, dehydration is the most efficient and economical means of preventing the hydrate formation in the trunk pipeline. The existing methods for gas dehydration in the field fall into two main groups: *absorption* (dehydration by liquid media) and *adsorption* (dehydration by solid media).

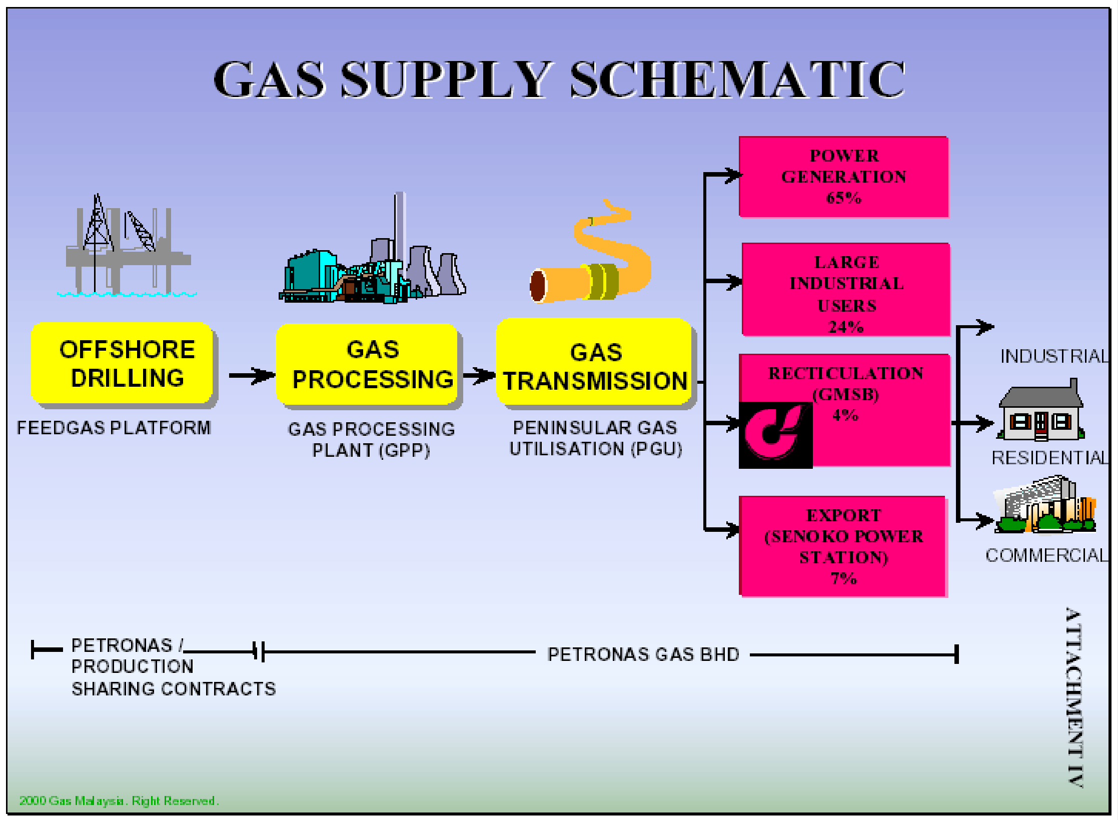
The dehydration is aimed at the depression of the water dew point below the minimal temperature that can be expected in the gas pipeline.
Gas dehydration by liquid media is most widely used in the gas industry.

Sweetening

Gas sweetening is a process that has to be executed to remove hydrogen sulphide (H_2S) from gasses. Gas sweetening is sometimes referred to as amine treating.

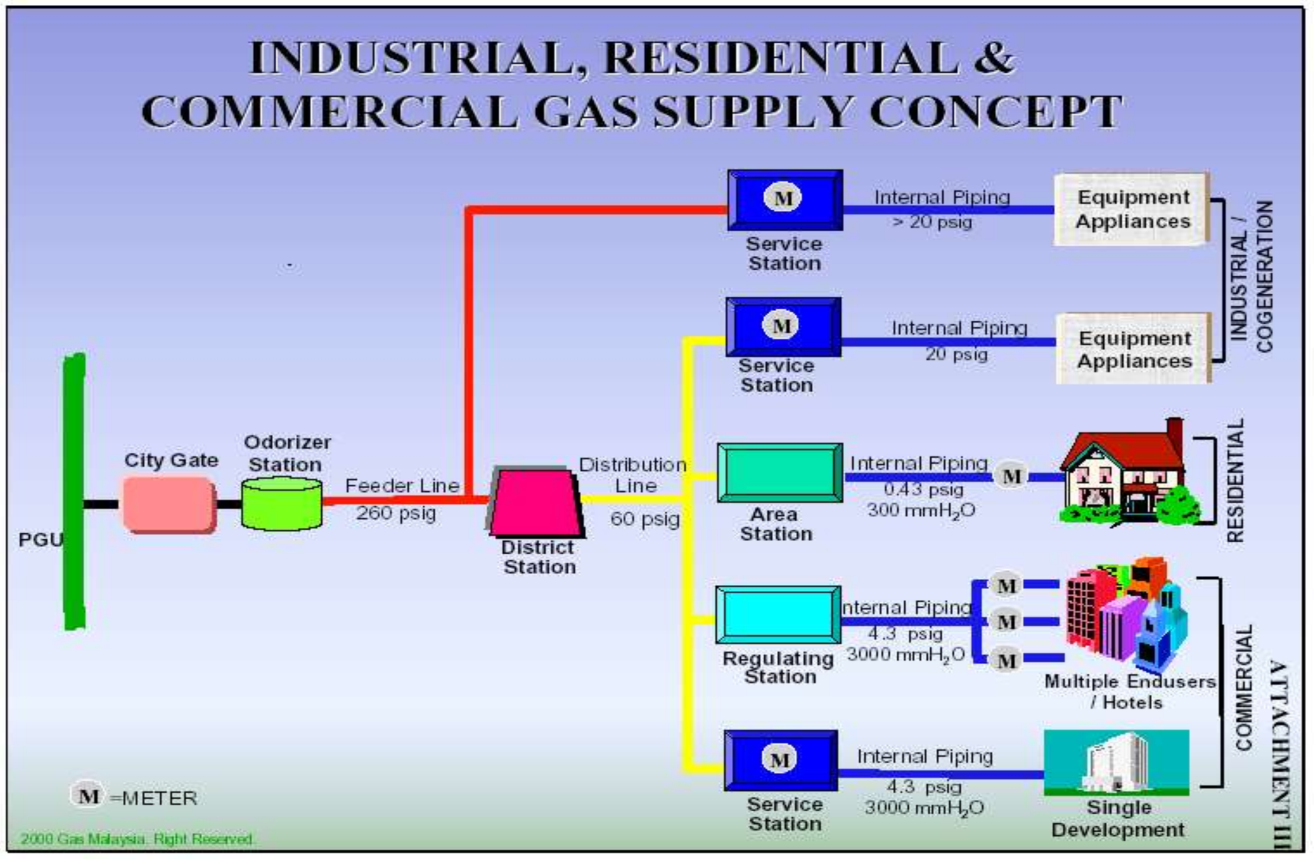
With absorption and chemical reactions it is possible to remove H_2S and CO_2 from natural gas and liquid hydrocarbon streams

Gas Transmission



High Pressure - 500 psig to 1000 psig (3400 – 6900 kPa)

Gas Distribution



Refining & GTL (Gas to Liquid)

Gas refining are processes of converting natural gas to products. Examples of these processes are catalytic conversion of gas to liquid products, such as methanol or fuels (Fischer-Tropsch) and cryogenic liquefaction to liquefied natural gas (LNG)

Boiling Liquid Expanding Vapour Explosion (BLEVE)

The BLEVE is an explosion due to flashing of liquids when a vessel with a high vapour pressure substance fails.

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