<u>(e) Natural Gas:</u>

-Natural gas is present in the earth and is often produced in association with the production of crude oil. Processing is required to separate the gas from petroleum liquids and to remove contaminants. First, the gas is separated from free liquids such as crude oil, hydrocarbon condensate, water and entrained solids. The separated gas is further processed to meet certain pipelines quality specifications with respect to water content, hydrocarbon dew point, heating value and hydrogen sulphide content. Generally, a gas sweetening plant removes hydrogen sulphide and other sulfur compounds

- Over 70% of the natural gas is formed by methane.

-It is Colorless, odorless and mostly constitutes methane which is a relatively unreactive hydrocarbon.

Utilization:

-Natural gas is widely used for different purposes such as space heating, electricity generation, industrial processes, agricultural, raw material for petrochemical industry, residential, commercial and utility markets

-On a gallon equivalent basis, natural gas costs less than gasoline, diesel fuel or any other alternative fuel. Natural gas currently supplies over 25% of the energy demand because of its quality.

-can either be stored on board a vehicle in tanks as compressed natural gas (CNG) at pressure of 16 to 25 bar or cryogenically cooled to a liquid state (-127 °C) as liquefied natural gas (LNG) at pressure of 70 to 120 bar. As a fuel and with a single throttle body injector it works best in an engine system. LNG is used in heavy duty vehicles where use of CNG would still entail space and load carrying capacity penalties. The fuel storage system of natural gas as LNG instead of CNG is less than half the weight and volume of CNG system. So, it can be easily transportable than CNG.

(i) CNG (Compressed Natural Gas)

-Natural gas consists of elements of compressor, some sort of compressed gas storage and dispensing unit of CNG into vehicles

-Two types of CNG refueling system- slow fill and fast fill. In slow fill system, several vehicles are connected to the output of the compressor at one time. These vehicles are then refilled over several hours of compressor operation. In fast fill systems, enough CNG is stored so that several vehicles can be refueled one after the other, just like refueling from a single gasoline dispenser

-The storage system of CNG is arranged as several tanks in cascade form. The CNG pressure in cascade is higher than the maximum storage pressure of the cylinder on the vehicle. The cascade attempts to deliver as much of its CNG to vehicles as possible before the pressure difference decreases to where the flow rate slows dramatically. A dryer should include in most CNG refueling systems to remove water vapor, impurities and hydrogen sulphide from natural gas before it is compressed. If water vapor is present then it can condense in the vehicle fuel system, causing corrosion especially if hydrogen sulphide is present. CNG driven vehicles with catalytic converter have less CO and HC emission but NOx emission is high

(ii) LPG (Liquefied Petroleum Gas)

-LPG is available in the market in two forms- one is propane and the other is butane. Propane is popular alternative fuel because of its infrastructure of pipe lines, processing facilities and storage for its efficient distribution and also it produces fewer emissions. Propane is produced as a byproduct of natural gas processing and crude oil refining

-Natural gas contains LPG, water vapor and other impurities and about 55% of the LPG is compressed from natural gas purification. LPG is a simple mixture of hydrocarbon mainly propane/propylene (C_3S) and butane/ butylenes (C_4S)

-Propane is an odorless, nonpoisonous gas which has lowest flammability range.

Utilization of LPG

LPG is used as a fuel in heating appliances and vehicles. It is increasingly used as an aerosol propellant and a refrigerant, replacing chlorofluorocarbons in an effort to reduce damage to the ozone layer

-In Europe, LPG is used as an alternative to electricity and heating oil (kerosene).It can also be used as power source for combined heat and power technologies (CHP). CHP is the process of generating both electrical power and useful heat from a single fuel source. This technology has allowed LPG to be used not just as fuel for heating and cooking, but also for de-centralized generation of electricity

-LPG has higher potential as an alternate fuel for IC engine.

Advantages of LPG

-Emission is much reduced by the use of LPG.

-LPG mixes with air at all temperatures.

-Uniform mixture can be supplied to all cylinders of multi-cylinder engine.

-Engine with high compression ratio (10:1) can use propane.

-There is cost saving of about 50% and longer life with LPG running engine.

Disadvantages of LPG

(i) A good cooling system is necessary because LPG vaporizer uses engine coolant to provide the heat to convert the liquid LPG to gas [2].

(ii) The weight of vehicle is increased due to the use of heavy pressure cylinder for storing LPG.

(iii) A special fuel feed system is required for LPG.

(iv) Requirement of safety device to prevent accident due to explosion of gas cylinders or leakage in the gas pipes.

(f) Producer Gas:

-Producer gas is a product of oxidation-reduction reactions of air with biomass. Biomass is chemically composed of elements C, H, O and some N and hence the oxidation results in products of combustion like CO_2 and H_2O. The molecules of O_2 in the air oxidises C and H to produce these products. The gases which are at high temperature due to partial oxidation pass through a bed of charcoal (which is produced because of oxidation reaction itself) and the reduction reaction of these gases with carbon leads to carbon monoxide and hydrogen

-Volumetric composition of producer gas is CO (16-20%), H_2 (16-18%), CO_2 (8-10%) and some traces of higher hydrocarbons. Producer gas has a high percentage of N_2, since air is used. So it has a low heat value. Density of producer gas is 0.9 to 1.2 kg/m^3

-Producer gas is used in reciprocating engines and furnace. It needs little air to burn stoichiometrically and raise the temperature to a value of 1500 K at normal temperature and pressure. It is also used to power gas turbines (which are well-suited to fuels of low calorific value), spark ignited engines (where 100% petrol fuel replacement is possible) or diesel internal combustion engines (where 40% - 15% of the original diesel fuel) is still used to ignite the gas.

(g) Blast Furnace Gas:

It is a byproduct of melting iron ore in steel plants. It principally consists of CO and contains low heat value similar to producer gas. It consists of about 60% nitrogen, 18-20% CO_2 and some amount of oxygen which are not flammable. It may be combined with natural gas or coke oven gas before combustion or a flame support with richer gas or oil is provided to sustain combustion. The auto ignition temperature of blast furnace gas is approximate 630 °C and it has Lower Explosive Limit (LEL) of 27% &Upper Explosive Limit (UEL) of 75% in an air-gas mixture at normal temperature and pressure. The gas is hazardous due to higher concentration of carbon monoxide [50].It should be cleaned properly because it contains lot of dust particles. Blast furnace gas depends upon types of fuel used and method of operating the blast furnace.

(h) Coke Oven Gas:

It is produced during the making of coke. It is also resulting from oxidation-reduction reactions of coal or coke with air and sometimes steams. It depends upon the type of coal used and operation method of oven. The composition of coke oven gas is H_2 (54% vol), CH_4 (24%), CO (8%), CO_2 (6%) and some traces of higher hydrocarbon and nitrogen. With the application of heat the heavier hydrocarbons are cracked and volatile portion of coal is driven off and results in high composition of $H_2$and CH_4. Its heat value per cubic meter is only about one half that of natural gas and density is 0.40 kg/m^3.

***General Fuel Specifications:**

Different properties of fuels have,

Relative density (specific gravity)
Fuel composition
Specific heating value
Flash point
Viscosity

Surface tension
Freezing point

(a) Relative density (specific gravity):
It is related to the measurement of the ratio of the weight of a given volume of fuel to the weight of the same volume of water, both at 20 ^{O}C and 101.325 kPa

For gasoline, the relative density is around 0.72 to 0.78 - which is equivalent to an API (American petroleum institute) range of 65 to 50,

ρ = 700 −800 [kg/m^3], for unleaded gasoline this value is higher due to the aromatics

For diesel fuel, ρ = 830 − 950 [kg/m^3]

(b) Fuel composition:

C and H: carbon content of aromatics is around 89 %, and of paraffins and naphthenes is around 86 %
Benzene: max allowable concentration is specified because it is highly toxic material, the level is 5 %
Sulphur content: HC fuels contain free sulphur, hydrogen sulphide and other sulphur compounds which are objectionable it is a corrosive element that can corrode fuel lines, carburettor and injection pump. It will unite with oxygen to form sulphur dioxide, which in presence of water at low T, forms sulphurous acid.

-It has low ignition T, promote knock in SI engines. limited to approx 250 ppm (50 ppm is aimed for low pollutant emitting vehicles)
Gum deposits: gasoline with unsaturated HCs forms gum in the engine, paraffin, naphthene and aromatic HCs also form some gum – it causes operating difficulties, sticking valves and piston rings, deposits in the manifold etc.
Water: both dissolved and free water can be present in gasoline, free water is undesirable because it can freeze and cause problems. Dissolved water is usually unavoidable during manufacture.
Lead: for leaded and unleaded gasoline max lead content is specified, lead causes pollution and destroys catalytic converters in the exhaust system.
Manganese: used for antiknock in gasoline (MMT), max amount is specified, 0.00025 to 0.03 gMn/L
Oxygenates: oxygenated compounds such as alcohols are used in gasoline to improve octane rating.
In USA gasohol (10% ethanol contains 3.5% oxygen), TBA and methanol up to 3.5% oxygen methanol up to 5% volume, MTBE up to 15% are used. In EC monoalcohols and ethers with atm boiling points lower than the final atm boiling point of gasoline in the standards can be used. Higher concentrations require modifications on the vehicles - carburator or fuel injection system must be modified to compensate for the oxygen content of the fuel. Blends with 15% methanol can be used.

(C) Specific heating value:

-Specific heating value, H_u is a measure of the energy content of the fuel per unit mass (kJ/kg or kcal/kg)

-Gaseous fuels sp heating value is given in terms of energy content per unit volume (kJ/liter or kJ/m^3, kcal/m^3)
-In IC engines lower heating value is given as the combustion products contain water in vapour form.
For gasoline and diesel fuel
H_u=42000-44000 kJ/kg or H_u=10200-10500 kcal/kg
-Heating value of the combustible air-fuel mixture is a decisive factor for engine performance.

(d) Flash point:
-Flash point is the lowest temperature of a sample at which the fuel vapour starts to ignite when in contact with a flame (ignition source).
-Marcusson method – fuel container is slowly heated, while the fuel vapour is in contact with an open flame – T is measured
-For gasoline it is 25 ^oC, diesel fuel 35 ^oC and heavy diesel 65 ^oC

(e) Viscosity:
-Viscosity is an important parameter for CI engines, also influences fuel metering orifices since Re is an inverse function of fuel viscosity lower the viscosity, smaller the diameter of the droplets in the spray.
-Below certain limits, low viscosity increases the leaks in the fuel system. It is a strong function of T – must be given at certain T values
at 50 ^oC, 1.5 – 5.0 Engler or 0.5 to 0.6 centistokes

(f) Surface tension:

-Surface tension is a parameter which effects the formation of fuel droplets in sprays
-increasing the surface tension will reduce mass flow and air-fuel ratio in gasoline engines
-lower the value, smaller the droplet diameter
diesel fuel value is in the range of 0.023 – 0.032 N/m
and for gasoline it is 0.019 – 0.023 N/m

(g) Freezing point:

-the precipitation of paraffin crystals in winter can lead to clogged filters. It can be prevented by either removing paraffins from the fuel or adding flow improvers (additives).
-Antifreezing properties are determined by its filterability.
-For gasoline freezing point is –65 ^oC and for diesel fuel –10 ^oC

***Important fuel specifications for gasoline**

(a) Gasoline volatility:

Benzene for example has vapor pressure of 0.022 MPa at 38 OC in a closed container of 38 OC, benzene evaporates until the partial p
has a value of 0.022 MPa, If T is raised to 80.5 OC, then saturation p
will be 0.1 MPa and will be constant during the boiling
For gasoline it is not possible to indicate a single value of evaporation T or vapor pressure.
Gasoline contains large number of compounds - up to about 400

It has a smooth distillation curve - with good fractionation efficiency

Low fractionation efficiency effects engine performance at different operating conditions:
If distillation curve is displaced downward, gasoline becomes more volatile - poor hot start, vapor lock, high evaporative losses

Gasoline distillation curve:
Gasoline having boiling point up to 70 OC controls ease of starting and hot weather problems such as vapor lock
Mid-range controls the driving in cold weathers, particularly at warm up period of engine. It also influences the ice forming in carburetor.
Back end of the curve contains all the heavier, high boiling point compounds and these have high heat content - they are important in improving fuel economy for fully warmed up engine.
Some of the heavier compounds may pass into the crankcase and dilute the crankcase oil. They are not readily combusted as the lighter compounds - cause combustion chamber deposits.

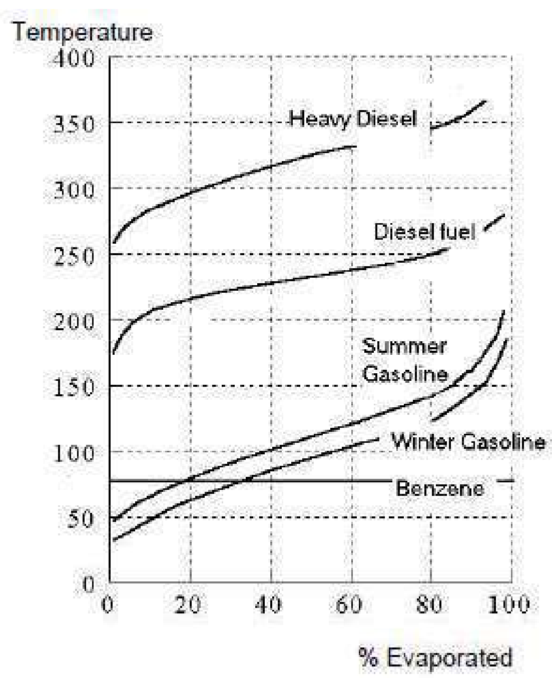

Fig. 12. Distillation curve

%10 evaporation point should be at low T for start up at cold temperatures - at hot weathers this may cause problems - vapor lock.
50% evaporation should be slightly above 100 OC at summer and slightly below 100 OC at winter. For warmed up engine conditions this point is not important.
90% evaporation must not be high - produces fuel film on intake manifold walls and dilutes lubricating oil. Back end of the curve must not exceed 215 OC.
Gasoline volatility should be arranged according to weather conditions -particularly ambient T. Altitude has some minor effect due to pressure changes.
It is also effected by the characteristics of the vehicle itself (drivability, fuel system design etc).

Cold starting:
For SI engines to start, A/F ratio must be within the ignitable range, ie in general must be between 7:1 to 20:1 by weight.

When the engine is cold, it is difficult to ignite lean mixtures, because fuel may not vaporize sufficiently - under these conditions the mixture is rich to bring it to ignitable range. This is done by the injection time or by the use of a choke with carburetted engines.

Measurement of gasoline volatility:

Tests usually define Reid Vapour Pressure - ASTM Distillation test and Vapour/Liquid ratio.

Reid vapour pressure - obtained at air-to-liquid ratio of 4:1 and temperature 37.8 ^oC.

Fuel is filled into a metal chamber which is connected to an air chamber and that is connected to a pressure gauge. The apparatus is immersed in water bath at 37.8 ^oC and is shaken until constant p is obtained - Reid VP

For gasoline allowable RVP is 0.7 bar in summer and 0.9 bar in winter (at 37.8 ^oC)

ASTM Distillation procedure - distillation rate is controlled by the heat input - distillation curve is plotted (temperature vs % evaporated).

(b)Antiknock quality of gasoline:

-Knock occurs when the unburnt gases ahead of flame front (the end gases) spontaneously ignite causing a sudden rise in pressure accompanied by a characteristic pinging sound – this result in a loss of power and can lead to damage the engine.

-Combustion chamber shape, spark plug location, ignition timing, end gas temperatures, in cylinder gas motion, air-fuel ratio of the mixture, fuel specifications etc. effects the occurrence of knock.

-Compression ratio of the engine also strongly effects knock. The higher the CR, the better the thermal efficiency - but the greater the tendency for knock to occur.

-Critical compression ratio - when knock starts. So higher fuel octane quality is required.

-Autoignition of the end gases causes a rapid increase of p, producing p waves which resonate in the combustion chamber at a frequency of between 5000 - 8000 Hz, depending on the geometry of the chamber

Knock results in an increase of T in the cylinder and causes a severe damage to engine components like cylinder head gasket, piston, spark plugs etc.

Octane number:

-In 1929 Octane scale was proposed by Graham Edgar. In this scale two paraffinic HCs have been selected as standards (PRF, primary reference fuels)- iso-octane (2-2-4 trimethyl pentane) with very high resistance to knock (arbitrary assigned a value of 100) and n-heptane with extremely low knock resistance (assigned a value of 0).

-Octane number of the fuel is the volume percentage of iso-octane in a blend with n-heptane (PRF), that shows the same antiknock performance as test fuel tested in standard engine and standard conditions.

-Test engine for determining Octane values, was developed by Cooperative Fuel Research Committee (CFR). It is a single cylinder, variable CR engine.

-Two different test conditions specifies the Research Octane Number (RON) and the Motor Octane Number (MON)

-Antiknock Index = (RON + MON) / 2

-TEL is added to the PRF to increase the ON above 100 or n-heptane is added to the sample to reduce ON below 100, then nonlinear extrapolation is applied

ON can be increased by antiknock agents - at less expense than modifying HC composition by refinery process.

Most effective agents are lead alkyls -

TEL - tetraethyl lead, $(C_2H_5)_4$ Pb

TML - tetramethyl lead,

MMT
addition of about 0.8 g lead per litre, provides a gain of about 10 ON in gasoline

***Important fuel specifications for diesel**

(a) Viscosity:

-Viscosity of a fluid indicates its resistance to flow - higher the viscosity, the greater the resistance to flow.
-It may be expressed as absolute viscosity (Poise, P) or kinematic viscosity (stoke, St).
-It varies inversely with temperature, usually given at 20 - 40 ^{O}C
-Fuel atomization depends on viscosity
2 - 8 mm^2/s (cSt) at 20 ^{O}C

-Lower the viscosity, smaller the diameter of the droplets in the spray

(b) Surface tension:

-Surface tension is a parameter which effects the formation of fuel droplets in sprays
-Lower the value, smaller the droplet diameter

-Diesel fuel 0.023 – 0.032 N/m

(c) Cetane number:

-Cetane number is used to specify the ignition quality of diesel fuel.
-Running on low Cetane number will produce cold start problems. Peak cylinder pressure, combustion noise and HC emissions will increase -more fuel will be injected before ignition, less time for combustion.
-Higher CN results in a sooner ignition - extremely high CN may ignite before adequate Fuel-Air mixing can take place - higher emissions. Power output can be reduced if burning starts too early.

Measurement of cetane number:
-Cetane number is measured by comparing the "ignition delay time" of the sample fuel with a mixture of cetane ($C_{16}H_{34}$) and alphamethyl naptane ($C_{10}H_7CH_3$). The Cetane percentage in the mixture gives the CN of the sample fuel.
-CN of the reference fuel cetane is arbitraryly set at 100, and of alphamethyl naptane at 0.
-CFR engine is used to measure the compression ratio at which ignition starts. CR is gradually increased while the engine is driven by an electric motor - a curve of CN vs critical CR is obtained.
-Inlet air temp is 30 ^{o}C and cooling water temp is at 100 ^{o}C
An easier and practical method to obtain Cetane Number is by calculating the Diesel Index.
Increasing the DI, increases the tendency to ignite.

$$DI = \frac{Annilin\ point\ [°\mathrm{F}] \times API[at\ 60\ °\mathrm{F}]}{100}$$

-AP is obtained by heating equal amounts of annilin and diesel fuel. While cooling down, the temp at which the annilin separates from the mixture is the AP

-Cetane number is in the range of,
50 - 60 for high speed Diesel engines
25 - 45 for low speed Diesel engines
Normal Diesel fuel CN is 40 - 55