

## UNIT 1

### MANUFACTURE OF FUELS AND LUBRICANTS.

Structure of petroleum, refining process, fuels, thermal cracking, catalytic cracking, polymerization, alkylation, isomerisation, blending, products of refining process, manufacture of lubricating oil base stocks, manufacture of finished automotive lubricants, distillation curve

## FUELS

### INTRODUCTION

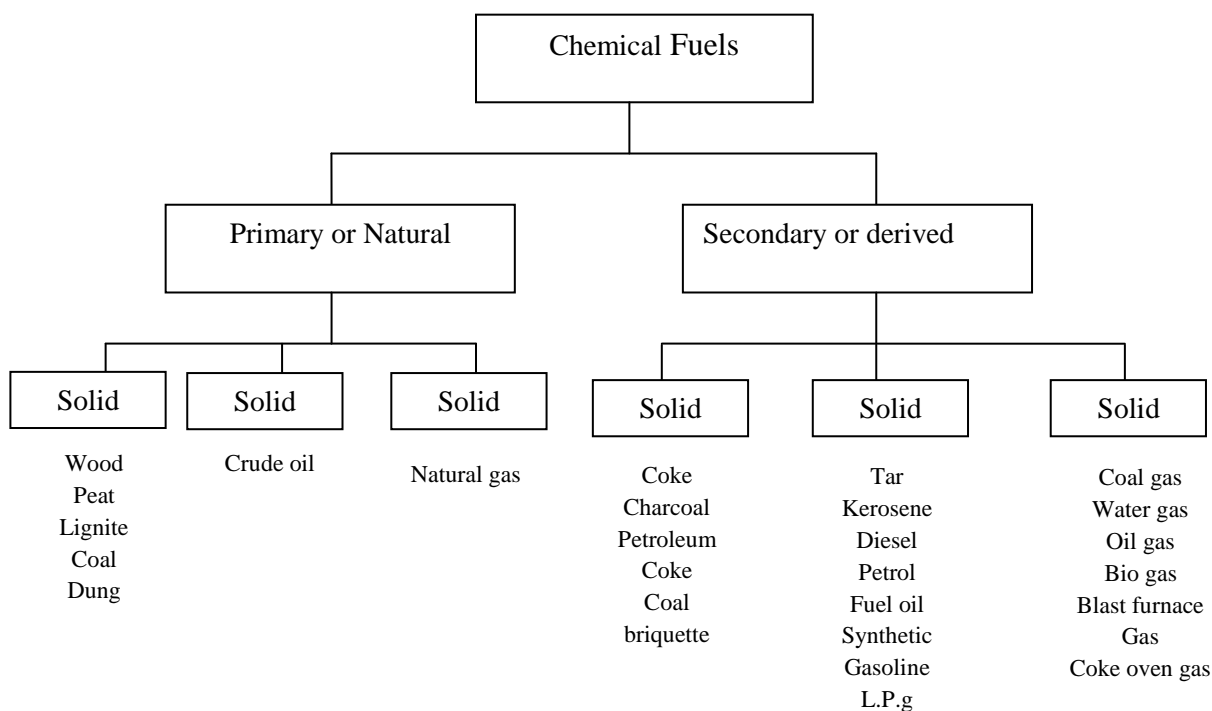
The engine converts the heat energy which is obtained from the chemical combination of fuel with the oxygen, into mechanical energy. Since the heat energy is derived from the fuel, the fundamental knowledge in types of fuels and their characteristics is essential in order to understand the combustion phenomenon.

Fuel is a combustible substance, containing carbon as main constituent, which on proper burning gives a large amount of heat, which can be used economically for domestic and industrial purposes. During the process of combustion of a fuel (like coal), the atoms of carbon, hydrogen, etc. combine with oxygen with the simultaneous liberation of heat at a rapid rate.



The primary or main source of fuels are coals and petroleum oils. These are stored fuels available in earth's crust and are, generally, called 'fossil fuels'.

### CLASSIFICATION OF FUELS



The fuels may be classified mainly into two types.

- primary or natural fuels
- secondary or derived fuels

(a) Primary or natural fuels are found in nature such as, for e.g., wood, peat, coal, petroleum, natural gas, etc.

(b) Secondary or derived fuels are those which are prepared from the primary fuels. For example, charcoal, coke, kerosene oil, diesel oil, petrol, coal gas, oil gas, producer gas, blast furnace gas, etc.

It is further subdivided into following three types. There are

- (i) Solid fuels                      (ii) Liquid fuels                      (iii) Gaseous fuels

## **SOLID FUELS**

The natural solid fuels are wood, peat, lignite or brown coal, bituminous coal and anthracite coal. The prepared solid fuels are wood charcoal, coke, briquetted coal and pulverised coal. Some of the solid fuels are discussed below.

### **Wood**

At one time it was extensively used as a fuel. It consists of mainly carbon and hydrogen. The wood is converted into coal when burnt in the absence of air. The average calorific value of the wood is 19700 kJ/kg

### **Peat**

It is a spongy humid substance found in boggy land. It may be regarded as the first stage in the formation of coal. It has a large amount of water contents (upto 30%) and therefore has to be dried before use. It has a characteristic odour at the time of burning, and has a smoky flame. Its average calorific value is 23000 kJ/kg.

### **Lignite or brown coal**

It represents the next stage of peat in the coal formation, and is an intermediate variety between bituminous coal and peat. It contains nearly 40% moisture and 60% of carbon. When dried, it crumbles and hence does not store well. Due to its brittleness, it is converted into briquettes, which can be handled easily. Its average calorific value is 25000 kJ/kg.

### **Bituminous coal**

It represents the next stage of lignite in the coal formation and contains very little moisture (4 to 6%) and 75 % to 90% of carbon. It is weather resistant and burns with a yellow flame. The average calorific value of bituminous coal is 33500 kJ/kg.

### **Anthracite coal**

It represents the final stage in the coal formation, and contains 90% or more carbon with a very little volatile matter. It is thus obvious, that the anthracite coal is comparative smokeless, and has very little flame. It possesses a high calorific value of about 36000 kJ/kg and therefore, very valuable for steam raising and general power purposes.

### **Wood charcoal**

It is made by heating wood with a limited supply of air in a temperature not less than 280° C. It is a well prepared solid fuel, and is used for various metallurgical processes.

### **Coke**

It is produced when coal is strongly heated continuously for 42 to 48 hours in the absence of air in a closed vessel. This process is known as carbonisation of coal. Coke is dull black in colour, porous and smokeless. It has high carbon content (85 to 90%) and has a higher calorific value than coal.

If the carbonisation of coal is carried out at 500° C to 700° C, the resulting coke is called lower temperature coke or soft coke. It is used as a domestic fuel. The coke produced by carbonisation of coal at 900° C to 1100°C, is known as hard coke. The hard coke is mostly used as a blast furnace fuel for extracting pig iron from iron ores, and to some extent as a fuel in cupola furnace for producing cast iron.

### **Briquetted coal**

It is produced from the finely ground coal by moulding under pressure with or without a binding material. The binding materials usually used are pitch, coal tar, crude oil and clay etc.

### **Pulverised coal**

The low grade coal with a high ash content, is powdered to produce pulverised coal. The coal is first dried and then crushed into a fine powder by pulverising machine. The pulverised coal is widely used in the cement industry and also in metallurgical processes.

## **LIQUID FUELS:**

Almost all the commercial liquid fuels are derived from natural petroleum (or crude oil). The liquid fuel consists of hydrocarbons. The natural petroleum may be separated into petrol or gasoline, paraffin oil or kerosene, fuel oils and lubricating oils by boiling crude oil at different temperatures and subsequent fractional distillation or by a process such as cracking. Some of the liquid fuels are discussed below.

### **1. Petrol or gasoline.**

It is the lightest and most volatile liquid fuel, mainly used for light petrol engines. It is distilled at a temperature from  $65^{\circ}\text{C}$  to  $220^{\circ}\text{C}$ .

### **2. Kerosene or paraffin oil.**

It is heavier but less volatile fuel than the petrol, and is used as heating and lighting fuel. It is distilled at a temperature from  $220^{\circ}\text{C}$  to  $345^{\circ}\text{C}$ .

### **3. Heavy fuel oils.**

The liquid fuels are distilled after petrol and kerosene are known as heavy fuel oils. These oils are used in diesel engines and in oil-fired boilers. These are distilled at a temperature from  $345^{\circ}\text{C}$  to  $470^{\circ}\text{C}$ .

## **Advantages of liquid fuels over solid fuels**

1. High calorific value.
2. Low storage capacity required.
3. Cleanliness and free from dust.
4. Practically no ashes.
5. Non-deterioration in storage.
6. Non-corrosion of boiler plates.

## **Disadvantages**

1. Highly expensive.
2. High risk of fire.
3. Expensive containers are required for storage and transport.

## **GASEOUS FUELS:**

### **1. Natural gas.**

The natural gas is, usually, found in or near the petroleum fields, under the earth's surface. The main constituents of natural gas are methane ( $\text{CH}_4$ ) and ethane ( $\text{C}_2\text{H}_6$ ). It has calorific value nearly  $21000 \text{ kJ/m}^3$ . It is used alternately or simultaneously with oil for internal combustion engines.

### **2. Coal gas.**

The quality of coal gas depends upon the quality of the coal used, temperature of the carbonisation and the type of plant. It is used in domestic lighting, furnaces and for running gas engines. Its calorific value is about  $21000 \text{ kJ/m}^3$  to  $25000 \text{ kJ/m}^3$ .

### **3. Producer gas**

It is obtained by the partial combustion of coal, coke, anthracite coal charcoal in a mixed air-steam blast. Its manufacturing cost is low, and has a calorific value of about  $5000 \text{ kJ/m}^3$  to  $6700 \text{ kJ/m}^3$ .

### **4. Water gas.**

It is a mixture of hydrogen and carbon monoxide and is made by passing steam over incandescent coke. As it burns with a blue flame, it is also known as blue water gas. The water gas is usually converted into carburetted (enriched) water gas by passing it through a carburetter into which a gas oil is sprayed.

It is, usually, mixed with coal gas to form town gas. The water gas is used in furnaces and for welding.

### **5. Mond gas.**

It is produced by passing air and a large amount of steam over waste coal at about  $650^\circ \text{C}$ . It is used for power generation and heating. It is also suitable for use in gas engine. Its calorific value is about  $5850 \text{ kJ/m}^3$ .

### **6. Blast furnace gas**

It is a by-product in the production of pig iron in the blast furnace. The gas serves as a fuel in steel works, for power generation in gas engines, for steam raising in boiler and for pre heating the blast for furnace.

It is extensively used as fuel for metallurgical furnaces. The gas leaving the blast furnace has a high dust content the proportion of which varies with the operation of the furnace. It has a low heating value of about  $3750 \text{ kJ/m}^3$ .

## 7. Coke oven gas.

It is a by-product from coke oven, and is obtained by the carbonisation of bituminous coal. Its calorific value varies from  $14500 \text{ kJ/m}^3$  to  $18500 \text{ kJ/m}^3$ . It is used for industrial heating and power generation.

### Advantages of gaseous fuels

1. The supply of fuel gas, and hence the temperature of furnace is easily and accurately controlled.
2. The high temperature is obtained at a moderate cost by pre-heating gas and air with combustion of waste gases.
3. They are directly used in internal combustion engines.
4. They are free from solid and liquid impurities.
5. They do not produce ash or smoke.
6. They undergo complete combustion with minimum air supply.

### Disadvantages

1. They are readily inflammable.
2. Air requires large storage capacity.

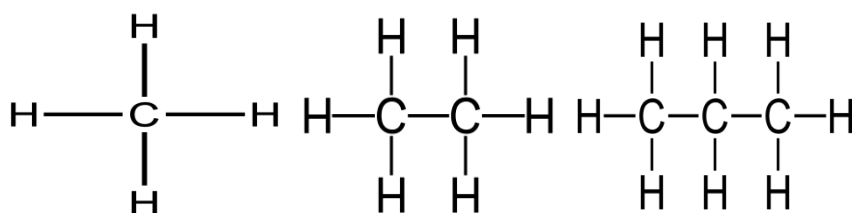
## STRUCTURE OF PETROLEUM

Usually the fuels used in internal combustion engines are complex mixtures of hydrocarbons made by refining petroleum. Petroleum as obtained from the oil wells is predominantly a mixture of many hydrocarbons with differing molecular structure. It also contains small amounts of sulphur, oxygen, nitrogen and impurities such as water and sand. The carbon and hydrogen atoms may be linked in different ways in a hydrocarbon molecule and this linking influences the chemical and physical properties of different hydrocarbon groups. The carbon to hydrogen ratio which is one of the important parameters and their nature of bonding determine the energy characteristics of the hydrocarbon fuels. Depending upon the number of carbon and hydrogen atoms the petroleum products are classified into different groups. They are

- (i) Paraffin series ( $\text{C}_n\text{H}_{2n+2}$ )
- (ii) Olefin series ( $\text{C}_n\text{H}_{2n}$ )
- (iii) Naphthene series ( $\text{C}_n\text{H}_{2n}$ )
- (iv) Aromatic series ( $\text{C}_n\text{H}_{2n-6}$ )

### (i) Paraffin series

The normal paraffin hydrocarbons are of straight chain molecular structure. They are represented by a general chemical formula  $C_nH_{2n+2}$ , where  $n$  is number of carbon atoms. In these hydrocarbons the valency of all the carbon atoms is fully utilized by single bonds with hydrogen atoms. Therefore the paraffins hydrocarbons are saturated compounds and their characteristics are very stable. The name of each member ends in 'ane' as in methane, propane, hexane, etc. n-Propane means normal propane.

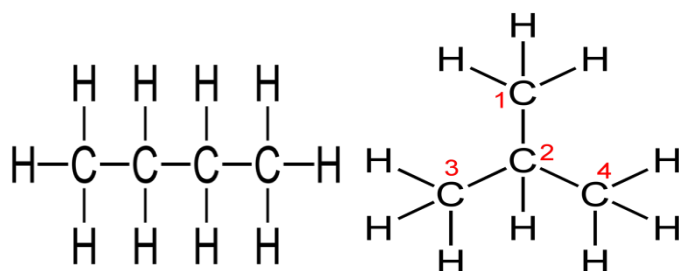


$n = 1$  : Methane

$n = 2$  : Ethane

$n = 3$  : Propane

A variation of the paraffin family consists of an open chain structure with an attached branch and is usually termed a branched chain paraffin. The hydrocarbons which have the same chemical formulae but different structural formulae are known as isomers.



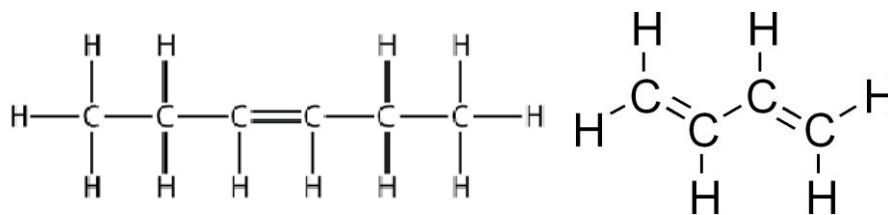
$n = 4$  : Butane

$n = 4$  : Iso Butane

Isobutane shown above has the same general chemical formula and molecular weight as butane but a different molecular structure and physical characteristics. It is called as isomer of butane and is known as isobutane. Isoparaffins are also stable compounds. The lower paraffins are gases, the higher being liquids and still higher, solids.

### (ii) Olefin series:

Olefins are also straight chain compounds similar to paraffins but are unsaturated because they contain one or more double bonds between carbon atoms. The names of hydrocarbons having one double bond end in 'ene' as in ethylene, butene, etc., and in 'adiene' for two double bonds as in butadiene, etc.



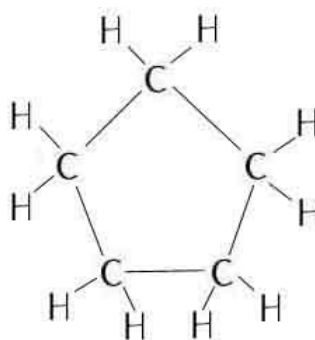
n=6: Hexene

n=6: Butadiene

The general formulae are  $C_nH_{2n}$  for mono-olefins (one double-bond) and  $C_nH_{2n-2}$  for the diolefins (two double-bonds).

### (iii) Naphthene series

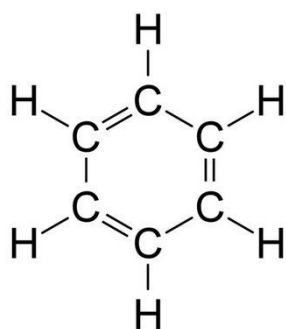
The naphthenes have the same chemical formula as the olefin series of hydrocarbons but have a ring structure and therefore often they are called as cyclo-paraffins. They are saturated and tend to be stable.



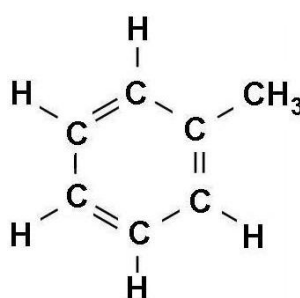
n = 5 : Cyclopentane

### (iv) Aromatic Series

Aromatic compounds are ring structured having a benzene molecule as their central structure and have a general chemical formula  $C_nH_{2n-6}$ . Though the presence of double bonds indicates that they are unsaturated, a peculiar nature of these double bonds causes them to be more stable than the other unsaturated compounds.



n = 6: Benzene



Toluene



Various aromatic compounds are formed by replacing one or more of the hydrogen atoms of the benzene molecules with an organic radical such as paraffins, naphthenes and olefins. By adding a methyl group ( $\text{CH}_3$ ). Benzene is converted to toluene ( $\text{C}_6\text{H}_5\text{CH}_3$ ) the base for the preparation of Trinitrotoluene (TNT) which is a highly explosive compound.

Family of Hydrocarbons	Chemical Formula	Molecular Structure	Saturated / Unsaturated	Stability
Paraffin	$\text{C}_n\text{H}_{2n+2}$	Chain	Saturated	Stable
Olefin	$\text{C}_n\text{H}_{2n}$	Chain	Unsaturated	Unstable
Naphthene	$\text{C}_n\text{H}_{2n}$	Ring	Saturated	Stable
Aromatic	$\text{C}_n\text{H}_{2n-6}$	Ring	Highly Unsaturated	Most unstable

#### General characteristics of hydrocarbon due to the molecular structure:

- ❖ Normal paraffins exhibit the poor antiknock quality when used in an SI engine. But the antiknock quality improves with the increasing number of carbon atoms and the compactness of the molecular structure. The aromatics offer the best resistance to knocking in SI Engines.
- ❖ For CI engines, the order is reversed i.e., the normal paraffins are the best fuels and aromatics are the least desirable.
- ❖ As the number of atoms in the molecular structure increases, the boiling temperature increases. Thus fuels with fewer atoms in the molecule tend to be more volatile.
- ❖ The heating value generally increases as the proportion of hydrogen atoms to carbon atoms in the molecule increases due to the higher heating value of hydrogen than carbon. Thus paraffin's have the highest heating value and the aromatics the least.

#### REFINING OF PETROLEUM

The process of (i) removing impurities and (ii) separating petroleum into more useful fractions with different boiling point range is known as refining of petroleum.

##### (i) Removal of impurities:

##### Step 1: Separation of Water (Cottrell's Process)

The crude oil from the oil well is an extremely stable emulsion of oil and salt water. The process of freeing oil from water consists in allowing the crude to flow between

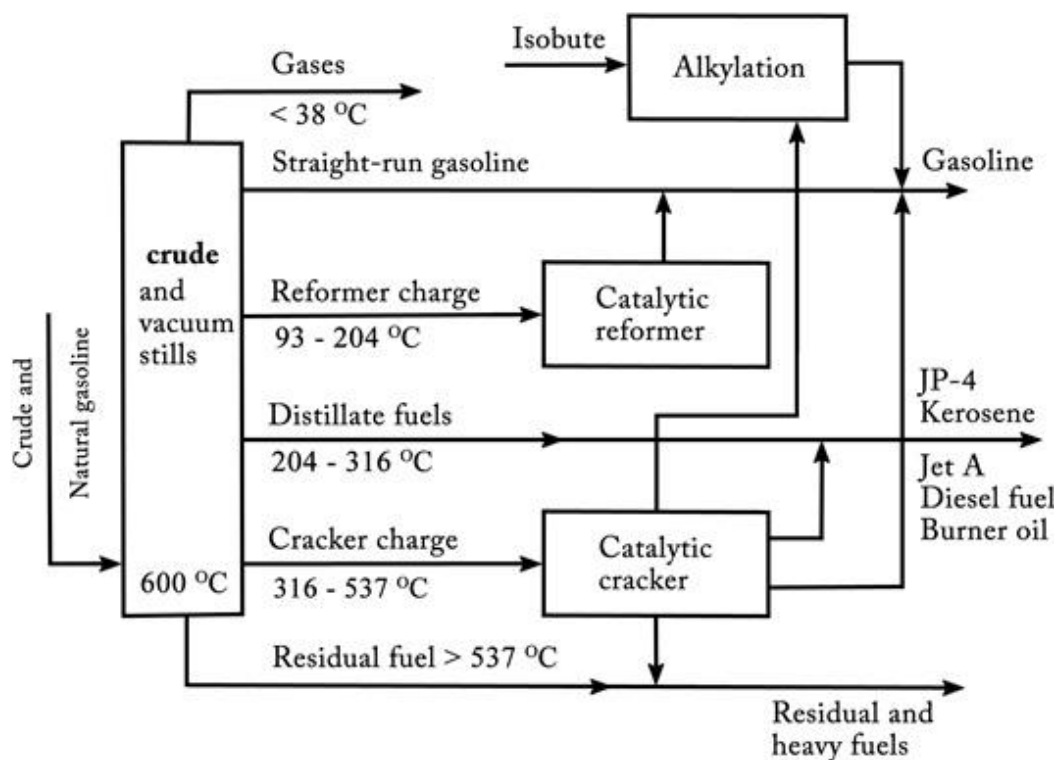
two highly charged electrodes. The colloidal water droplets coalesce to form large drops, which separate out from the oil.

### Step2: Removal of harmful sulphur compounds

It involves in treating oil with copper oxide. A reaction occurs with sulphur compounds, which results in the formation of copper sulphide, which is then removed by filtration.

### (ii) Fractional distillation

The crude oil is separated into gasoline, kerosene, fuel oil etc. by the process of fractional distillation. In the first step, the petroleum is passed through a separator in which the gases are removed and a product known as natural gasoline is obtained. The liquid petroleum is then vapourized in a still, at temperatures of  $600^{\circ}\text{C}$  and the vapour is admitted at the bottom of the fractionating tower. The vapour is forced to pass upwards along a labyrinth like arrangement of plates which direct the vapour through trays of liquid fuel maintained at different temperatures. The compounds with higher boiling points get condensed out at lower levels while those with lower boiling points move up to higher levels where they get condensed in trays at appropriate temperature. Generally the top fraction is called the straight run gasoline and the other fractions, kerosene, diesel oil, fuel oil etc., are obtained in the increasing range of boiling temperatures.



Refining process

The gasoline demand is much more than that of other petroleum products. This led to the development of refinery processes to convert unwanted streams of crude into salable products and to upgrade quality of these streams. Many processes can be used to convert some of these fractions to compounds for which there is a greater demand.

Some of the main refinery processes are as follows

(i) Cracking consists of breaking down large and complex hydrocarbon molecules into simpler compounds. Thermal cracking subjects the large hydrocarbon molecules to high temperature and pressure and they are decomposed into smaller, lower boiling point molecules.

(ii) Catalytic cracking using catalysts is done at a relatively lower pressure and temperature than the thermal cracking. Due to catalysis, the naphthenes are cracked to olefins, paraffins and olefins to isoparaffins needed for gasoline. Catalytic cracking gives better antiknock property for gasoline as compared to thermal cracking.

(iii) Hydrogenation consists of the addition of hydrogen atoms to certain hydrocarbons under high pressure and temperature to produce more desirable compounds. It is often used to convert unstable compound to stable ones.

(iv) Polymerization is the process of converting olefins, the unsaturated products of cracking, into heavier and stable compounds.

(v) Alkylation combines an olefin with an isoparaffin to produce a branched chain isoparaffin in the presence of a catalyst.

#### Alkylation

Example: isobutylene + isobutane  $\longleftrightarrow$  iso-octane

(vi) Isomerization changes the relative position of the atoms within the molecule of a hydrocarbon without changing its molecular formula. For example, isomerization is used for the conversion of n-butane into isobutane for alkylation. Conversion of n-pentane and n-hexane into isoparaffins to improve knock rating of highly volatile gasoline is another example.

(vii) Cyclization joins together the ends of a straight chain molecule to form a ring compound of the naphthene family.

(vii) Aromatization is similar to cyclization, the exception being that the product is an aromatic compound.

(viii) Reformation is a type of cracking process which is used to convert the low antiknock quality stocks into gasoline of higher octane rating. It does not increase the total gasoline volume.

(ix) Blending is a process of obtaining a product of desired quality by mixing certain products in some suitable proportion.

## **PRODUCTS OF REFINING PROCESS:**

### **(i) Natural Gas:**

Natural gas is found dissolved in petroleum or in huge amounts under earth surface in oil and gas bearing areas. Natural gas is made up mainly of the paraffinic compound methane, a small amount of propane, ethane, butane and other light hydrocarbons plus some nitrogen and oxygen. When natural gas occurs along with petroleum in oil wells, it is called wet gas. On the other hand, when the gas is associated with crude oil, it is called dry gas.

#### **Uses:**

- ❖ It is an excellent domestic fuel and can be conveyed over very large distances in pipelines.
- ❖ It has been recently used in the manufacture of a number of chemicals by synthetic processes

### **(ii) LPG:**

Liquefied petroleum gas (LPG) or bottled gas or refinery gas is obtained as a by-product, during the cracking of heavy oils or from natural gas. It is stored in liquid form in special cylinders at a pressure of about 100psi (700 kpa) and the engine is provided with a special fuel system. Its calorific value is about  $27800 \text{ kcal/m}^3$ .

The main constituents of LPG are n-butane, isobutane, butylene and propane, with little or no propylene and ethane.

#### **Advantages:**

- ❖ Better mixing with air and improved distribution, which means lesser emissions.
- ❖ No need of a fuel pump.
- ❖ No carbon deposits.
- ❖ No crank case dilution because of vapour form. This means lesser oil consumption.
- ❖ High octane rating.
- ❖ Less engine wear.

#### **Disadvantages:**

- ❖ Special fuel system has to be provided.

- ❖ Heavy pressure cylinders increase the vehicle weight unnecessarily.
- ❖ Hard to start in winter.

### **(iii) Gasoline**

Gasoline is the lightest liquid petroleum fraction. All material boiling up to 200°C is generally considered as gasoline. This is mixture of a number of hydrocarbons (more than 40). The composition depends upon the crude oil and refining process.

Gasoline lies in specific gravity range 0.70 to 0.78. This covers most of fuels used for spark-ignition engines. Its calorific value is about 47102 kJ/kg

### **(iv) Kerosene.**

The kerosene has heavy fraction than gasoline. Its boiling range is 150°C to 300°C and the specific gravity range is 0.78 to 0.85. Its calorific value is about 46474 kJ/kg

### **(v) Distillate.**

The distillate is slightly heavier than kerosene. These are used as tractor fuels and domestic fuels.

### **(vi) Diesel Oils.**

Diesel oils are fuels which lie between kerosene and lubricating oils. These cover a wide range of specific gravity and boiling point. Boiling range is 200 to 370°C. These form the fuels for compression ignition engines.

### **(vii) Fuel Oils.**

Fuel oils are similar to diesel fuel in specific gravity and distillation range but their composition varies in a range wide than those of diesel fuels. These are used as industrial fuels.

### **(viii) Lubricating Oils.**

Lubricating oils are made up of heavy distillate of petroleum and residual oil. These are used for lubricating purposes.

### **(ix) Tar and Asphalt.**

Tar and asphalt are solid or semi-solid undistilled products of petroleum.

### **(x) Petroleum Coke.**

Petroleum coke is used as solid industrial fuel.

## **MANUFACTURING OF LUBRICATING OIL BASE STOCK PROCESSES**

The manufacture of lubricant base oils consists of five basic steps: 1) distillation and 2) deasphalting to prepare the feedstocks, 3) solvent or hydrogen refining to improve viscosity index and remove undesirable constituents, 4) solvent or catalytic dewaxing to remove wax and improve the low temperature properties of paraffinic base oils and 5) clay or hydrogen finishing to improve the colour, stability and quality of the lubricant base stocks.

### **Distillation**

In a lubricant base oil and wax manufacturing plant, crude oil is first distilled in an atmospheric distillation unit (ADU) to remove gases, gasoline, naphtha's, kerosene and light gas oil. The atmospheric residuum (reduced crude) is then fractionated in a vacuum distillation unit (VDU) into fractions of the desired viscosity and flash for further processing.

### **Deasphalting**

The vacuum residuum contains recoverable lubricant stock of high viscosity mixed with asphalt and resins. This oil is separated from the asphalt and resins using propane deasphalting, an extractive precipitation process.

### **Refining**

The deasphalted oil and the distillates usually contain undesirable constituents such as aromatics and naphthenes and these must be removed to yield an oil of high viscosity index and high lubricating quality. These undesirable constituents are removed by treating the stocks separately with a solvent (furfural, phenol, N-methyl-2-pyrrolidone or liquid sulphur dioxide) which selectively removes (extracts) these constituents from the oil. The extract, containing the undesirable materials which have been removed, may be used as fluid catalytic cracking unit (FCCU) or coker feedstock, blended into fuel oil, hydrocracked or used as rubber extender oil.



hard wax and a soft wax. The soft wax or foots oil is frequently used as a seal oil or as FCCU feedstock.

A selective hydrocracking process called catalytic dewaxing is used as an alternative to solvent dewaxing and hydrogen finishing for the removal of wax and finishing of lubricant base oils. No wax is produced from catalytic dewaxing unless the desired wax is removed by solvent dewaxing prior to catalytic dewaxing.

### **Finishing**

Both the dewaxed oil and the product wax are normally hydrofinished or treated with adsorbent clay to meet the colour and oxidation stability requirements of a marketable product. A severe hydrogen finishing process, hydrotreating, is used to remove large amounts of sulphur and nitrogen and trace impurities in the manufacture of food grade wax and pharmaceutical grade white oils or to stabilize base oils produced by hydrocracking. Solvent refining is also used to stabilize hydrocracked base oils.

### **Product Formulation**

The finished base oils are then blended with one another and with additives to produce the desired high grade lubricants. Speciality oils such as refrigeration oils and white oils are manufactured using the conventional processes in conjunction with acid and clay treating or hydrotreating processes.

### **DISTILLATION CURVE:**

A distillation curve is essentially a plot of boiling temperature vs. cumulative percent volume evaporated from the sample during heating. This type of plot can be used to distinguish quickly between one or several product types. The distillation curve for SI engine fuel and CI engine fuels are discussed below in detail.

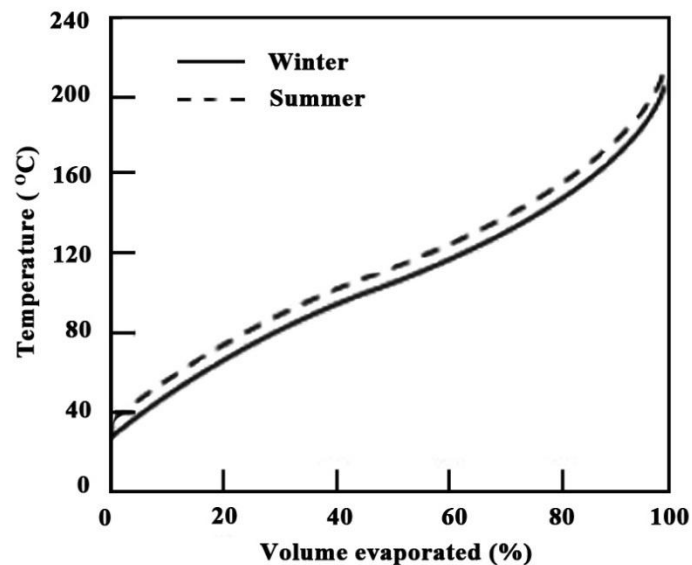
### **SI ENGINE FUELS:**

Volatility is one of the main characteristic properties of gasoline which determines its suitability for use in an SI engine. Since gasoline is a mixture of different hydrocarbons, volatility depends on the fractional composition of the fuel. The usual practice of measuring the fuel volatility is the distillation of the fuel in a special device at atmospheric pressure and in the presence of its own vapour. The fraction that boils off at a definite temperature is



measured. The characteristic points are the temperatures which 10, 40, 50 and 90% of the volume evaporates as well as the temperature at which boiling of the fuel terminates.

A certain part of the gasoline should vapourize at the room temperature for easy starting of the engine. Hence, the portion of the distillation curve between about 0 and 10% boiled off have relatively low boiling temperatures. As the engine warms up, the temperature will gradually increase to the operating temperature. Low distillation temperatures are desirable throughout the range of the distillation curve for best warm-up.



**Distillation curve for SI engine fuels**

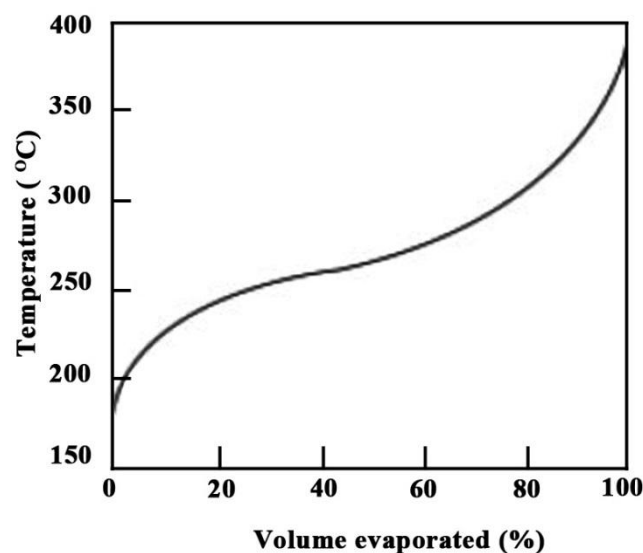
In order to obtain good vapourization of the gasoline, low distillation temperatures are preferable in the engine operating range. Better vapourization tends to produce both more uniform distribution of fuel to the cylinders as well as better acceleration characteristics by reducing the quantity of liquid droplets in the intake manifold.

Liquid fuel in the cylinder causes loss of lubricating oil (by washing away oil from cylinder walls) which deteriorates the quality of lubrication and tends to cause damage to the engine through increased friction. The liquid gasoline may also dilute the lubricating oil and weaken the oil film between rubbing surfaces. To prevent these possibilities, the upper portion of the distillation curve should exhibit sufficiently low distillation temperatures to insure that all gasoline in the cylinder is vapourized by the time the combustion starts.

High rate of vapourization of gasoline can upset the carburettor metering or even stop the fuel flow to the engine by setting up a vapour lock in the fuel passages. This characteristic, demands the presence of relatively high boiling temperature hydrocarbons throughout the distillation range.

### **CI ENGINE FUELS:**

The fuel should be sufficiently volatile in the operating range of temperature to produce good mixing and combustion. The fuel should help in starting the engine easily. This requirement demands high enough volatility to form a combustible mixture readily and a high cetane rating in order that the self-ignition temperature is low.



**Distillation curve for CI engine fuels**