# UNIT-4

## PROPERTIES AND RATING OF FUELS

Types of fuels, liquid and gaseous fuels, heating value of fuels, higher and lower heating values, chemical structure of hydro-carbons SI engine fuels, volatility characteristics, desirable characteristics of SI engine fuels, knock rating and additives, alternate fuels for SI engines, CI engine fuels, desirable characteristics, Cetane rating, alternate fuels for CI engines, biodiesels

### Types of Fuels

Since the heat energy is derived from the fuel, a fundamental knowledge of the types of fuels and their characteristics is essential to understand the combustion phenomenon.
The characteristic of fuel has a considerable influence on the design, efficiency, output and particularly the reliability and durability of the engine. Further, the fuel characteristics play an important role in the atmospheric pollution caused by the automobile engines.

Internal combustion engines can be operated on different types of fuels such as

- Solid fuels
- Liquid fuels
- Gaseous fuels

The design of the engine usually depends upon the type of fuel used.

### Solid fuels

This type of fuel was used in early engines. During the initial stages of engine development, solid fuels (such as finely powdered coal) were used. However, due to the problem of handling the fuel as well as in disposing off the solid residue or ash (after combustion), solid fuels find little practical application today.

- Further, there are storage and feeding problems associated with solid fuels as compared to gaseous and liquid fuels.
- However, attempts are being made to produce gaseous or liquid fuels from charcoal for their use in engines.

### Liquid fuels

The liquid fuels are mostly used in modern internal combustion engines. Basically, they are the derivatives of liquid petroleum. The commercial types are:

- Benzyl
- Alcohol
- Petroleum products

Petroleum (obtained from crude oil) is a mixture of many hydrocarbons with varying molecular structure. It also contains small amounts of

- Sulphur
- Oxygen
- Nitrogen
- Impurities (such as water, sand etc.)

**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**

Gaseous fuels are ideal for internal combustion engines. They mix more homogeneously with air. However, their use is restricted in automobiles due their storage and handling problems.

Gaseous fuels are suitable for stationary power plants near the source of availability of the fuel. They can be liquefied under pressure to reduce the storage volume, but this process is very expensive and risky.

**Advantages of gaseous fuels**

1. The supply of fuel gas, and hence the temperature of furnace is easily and accurate 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.

**Heating value**

For fuels where the precise fuel composition is not known, the enthalpy of the reactants cannot be determined from the enthalpies of formation of the reactant species. The ***heating value*** of the fuel is then measured directly.

The heating value QHv or calorific value of a fuel is the magnitude of the heat of reaction at constant pressure or at constant volume at a standard temperature [usually $25^{o}C$ **(77"F)** for the complete combustion of unit mass of fuel.

Complete combustion means that all carbon is converted to CO, all hydrogen is converted to H and O**,** and slny sulfur present is converted to SO,. The heating value is usually expressed in joules per kilogram or joules per kilomole of fuel.

The term ***higher heating value*** QHHv ( gross heating value) is used when the H,O formed is all condensed to the liquid phase; the term ***lower heating value*** QLHv (or net heating value) is used when the H,O formed is all in the vapor Phase.

Heating value of fuels are measured in calorimeters. For gaseous fuels, it is most convenient and accurate to use a continuous-flow atmosphere pressure calorimeter.

**CHEMICAL STRUCTURE OF PETROLEUM**

Depending upon the number of carbon and hydrogen atoms the petroleum products are classified into different groups. They are

(i) Paraffin series ( $C_nH_{2n+2}$ )

(ii) Olefin series ( $C_nH_{2n}$ )

(iii) Naphthene series ($C_nH_{2n}$)
(iv) Aromatic series ($C_nH_{2n-6}$)

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 ($CH_3$). Benzene is converted to toluene ( $C_6H_5CH_3$ ) 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 | $\mathbf{C_nH_{2n+2}}$ | Chain | Saturated | Stable |
| Olefin | $\mathbf{C_nH_{2n}}$ | Chain | Unsaturated | Unstable |
| Naphthene | $\mathbf{C_nH_{2n}}$ | Ring | Saturated | Stable |
| Aromatic | $C_nH_{2n-6}$ | Ring | Highly Unsaturated | Most unstable |

SI engine fuels
Gasoline which is mostly used in the present day SI engines is usually a blend of several low boiling paraffin, naphthenes and aromatics in varying proportions. Some of the important qualities of gasoline are discussed below.

- Volatility
- Starting and warm up
- Operating Range Performance
- Crank case dilution
- Vapour lock characteristics
- Antiknock quality
- Gum Deposits
- Sulphur Contents.

**Volatility**
It is the most important characteristics of a SI engine fuel. Volatility is a physical concept that loosely defined as the tendency to evaporate at a temperature lower than their boiling temperature. It is the most dominant factor that controls the air-fuel ratio inside the combustion chamber.
One of the most important requirements for proper and smooth combustion is the availability of a highly combustible air-fuel mixture at the moment of the start of the ignition inside the combustion chamber.
A highly volatile (of low molecular weight ) fuel generates a rich fuel air ratio at low starting temperature, to satisfy the criteria at the starting of the ignition. But, it will create another problem during running operation; it creates vapour bubble which choked the fuel pump delivery system. This phenomenon is known as vapour lock.
A vapour lock thus created restricts the fuel supply due to excessive rapid formation of vapour in the fuel supply system of the carburetor. High volatility of fuel can also result in excessive evaporation during storage in a tank which will also pose a fire hazards.Low volatile fuel like kerosene and distillates can be used for SI engines for tractors.

**Starting and warm up**

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 0 and 10% boiled off have relatively low boiling temperature. As the engine warms up, the temperature will gradually increase to the operating temperature.

**Operating Range Performance**

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

**Crank case dilution**

Liquid fuel in the cylinder causes loss of lubricating oil( by washing away oil from the 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 this situation, the upper portion of the distillation curve should exhibit sufficiently low distillation temperatures to ensure that all gasoline in the cylinder is vapourized by the time the combustion starts.

**Vapour lock characteristics**

High rate of vapourisation of fuel can upset the carburetor 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 throughout the distillation range.

**Antiknock quality**

Abnormal burning or detonation in an SI engine combustion chamber causes a very high rate of energy release, excessive temperature and pressure inside the cylinder adversely effects its thermal efficiency. Therefore, the characteristic of fuel should be such that it reduces the tendency to detonation and this property is called its antiknock property. The antiknock property of a fuel depends on the self-ignition characteristics of its mixture and varies largely with the chemical composition and molecular structure of fuel. In general, the best SI engine fuel will be that having the highest antiknock property, since this permits the use of higher compression ratios and thus the engine thermal efficiency and the power output can be greatly increased.

**Gum deposits**

Reactive hydrocarbons and the impurities in the fuel have a tendency to oxidize and form liquid and solid gummy substances. Unsaturated hydrocarbons are more prone to form gum deposits. Gum deposits may lead to clogging of carburetor jets and enlarging of the valve stems, cylinders and pistons.

**Sulphur content**

Hydrocarbon fuels may contain free sulphur, hydrogen sulphide and other sulphur compounds which are objectionable for several reasons. The sulphur is the corrosive element of the fuel that can corrode fuel lines, carburetors and injection pumps and it will unite with oxygen to form sulphur dioxide that, in presence of water at low temperatures, may form sulphurous acid. Since sulphur has a low ignition temperature, the presence of sulphur can reduce the self-ignition temperature, then promoting knock in the SI engine.

**Important characteristics of SI engine fuels**

Every SI engines are designed for a particular fuel having some desired qualities. For a good performance of a SI engine the fuel used must have the proper characteristics.The followings are requirements of a good SI engine fuels or Gasolines.

- It should readily mix with air to make a uniform mixture at inlet, ie. it must be volatile
- It must be knock resistant
- It should not pre-ignite easily
- It should not tend to decrease the volumetric efficiency of the engine.
- It should not form **gum** and **varnish**
- Its Sulphur content should be low as it is corrosive
- It must have a high calorific value

**Rating of SI engine fuels:-**

The knock resistance is the most important characteristic of the fuel for SI engine. The fuels differ widely in their ability to resist knock depending on their chemical composition. In addition to the chemical properties of the hydrocarbons in the fuel other operating parameters such as fuel-air ratio, ignition timing, dilution, engine speed, shape of combustion chamber, ambient conditions, compression ratio etc. affect the tendency to knock in the engine cylinder. Therefore, in order to determine the knock resistance characteristic of the fuel, the engine and its operating variables must be fixed at standard values.

Here also there are two reference fuels viz. iso-octane ($C_8H_{18}$) chemically being a very god antiknock fuel, has been assigned an octane number of 100 and normal heptane ($C_7H_{16}$), it has very poor antiknock qualities and is assigned an octane number of 0.

Def. The octane number of a fuel is defined as the percentage, by volume, of iso-octane in a mixture of iso-octane and normal heptanes, which exactly matches the knocking intensity of the fuel in standard engine under a set of standard operating conditions.

The octane number at the higher range of scale will produce greater antiknock effect compared to the same unit at the lower end of the scale e.g. octane number increase from 90 to 91 produces greater antiknock effect than a similar increase from 30 to 31. The addition of some chemicals like tetra ethyl lead(TEL) to iso-octane produces fuels of greater antiknock qualities.

**Antiknock Quality**

Abnormal burning/detonation in SI engine causes a very high rate of energy release, temperature and pressure. This adversely affects the thermal efficiency. The fuel characteristics should resist this tendency. This property of fuel is called its antiknock quality.
With no self-ignition, the pressure force on piston follows a smooth curve, resulting in smooth engine operation. When self-ignition occurs, pressure forces on piston are not smooth and engine knock occurs.

**Gasoline additives**

| Additives | Type | Function |
|---|---|---|
| Oxidation inhibitors | Aromatic amines and phenols | Inhibit gum formation and oxidation |
| Corrosion inhibitors | Carboxylic acids and carboxylates | Inhibit corrosion of ferrous metals |
| Metal deactivators | Chelating agent | Inhibit gum formation Catalyzed by certain metals |
| Anti-icing additives | Surfactants and glycols | Prevent icing in carburetor and fuel system |
| Detergents | Amines and amine carboxylates | Prevent deposits in carburetor throttle body |
| Deposit control additives | Polybutene amines Polyether amines | Remove and prevent deposits throughout carburetor intake ports and valves |
| Blending agents | Ethanol, methanol, tertiary butyl alcohol, methyl tertiary ether | Extend gasoline supply, increase apparent octane quality with some loss in mileage |
| Antiknock compounds | Lead alkykl, organo-manganese compounds | Increase octane quality |

**CI Engine Fuels**

**Knock characteristics**

Knock in the CI engine occurs because of an ignition lag in the combustion of the fuel between the time of injection and the time of actual burning. As the ignition lag increases, the amount of fuel accumulated in the combustion chamber increases and when combustion actually takes place, abnormal amount of energy is suddenly released causes an excessive rate of pressure rise which results in an audible knock. Hence, a good CI engine fuel should have a short ignition lag

and will ignite more readily. Furthermore, ignition lag affects the starting, warm up, and leads to the production of exhaust smoke in CI engine. The present day measure in the cetane rating, the best fuel in general, will have a Cetane rating sufficiently high to avoid objectionable knock.

**Volatility**

The fuel should be sufficiently volatile in the operating range of temperature to produce good mixing and combustion.

**Starting Characteristics**

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.

**Smoking and odor**

The fuel should not promote either smoke or odour in the engine exhaust. Generally, good volatility is the first prerequisite to ensure good mixing and therefore complete combustion.

**Viscosity**

CI engine fuel should be able to flow through the fuel system and the strainers under the lowest operating temperatures to which the engine is subjected to.

**Corrosion and Wear**

The fuel should not cause corrosion and wear of the engine components before or after combustion. These requirements are directly related to the presence of sulphur, ash and residue in the fuel.

**Handling Ease**

The fuel should be a liquid that will readily flow under all conditions that are encountered in actual case. This requirement is measured by the pour point and the viscosity of the fuel. The fuel should also have a high flash point and a high fire point

**Rating of fuels:-**

Rating of fuels is normally done for their antiknock qualities. The rating of fuels is done by defining two parameters cetane number and octane number for diesel and gasoline respectively. Here the detailed description of the rating is given.

**Rating of CI engine fuels:-**

The knock resistance depends on chemical properties as well as on the operating and design conditions of the engine. So the knock rating of a diesel fuel is found by comparing the fuel at a

specific condition with primary reference fuels. The reference fuels are normal cetane C16H34, which has been assigned a cetane number of 100 and alpha methyl naphthalene, C11H10, with a cetane number of 0.

Def. Cetane number of a fuel is defined as the percentage by volume of normal cetane in a mixture of normal cetane and alpha methyl naphthalene which has the same ignition characteristics (ignition delay) as the test fuel when combustion is carried out in a standard engine under specified operating conditions.

The knock should be directly related to the ignition delay as it is the major factor in controlling of the autoignition in the CI engine. Knock resistance property of a diesel oil can be improved by adding small quantities of compounds like amyl nitrate, ethyl nitrate or ether.

**Additives**

Some compounds called additives or dopes are used to improve the combustion properties of fuels. The main combustion problems that arise when the operating conditions become severe are knocking and surface ignition. That can be tackled by a lot of ways of which one is using additives.

- For an additive to be acceptable, it must satisfy some basic requirements. These are as follows:-
- It must be affective in desired reaction that is knock resistance or surface ignition or both.
- It should be soluble in fuel under all conditions.
- It should be stable in storage and have no adverse effect on fuel stability.
- It should be in the liquid phase at normal temperature, and volatile to give rapid vaporization in the manifold.
- It must not produce harmful deposits.
- Its water solubility must be minimum to minimize handling loses.

**Automotive diesel fuel additives**

| Additive | Type | Function |
|---|---|---|
| Detergents | Polyglycols, basic nitrogen-containing surfactants | Prevent injector deposits, increase injector life |
| Dispersants | Nitrogen-containing surfactants | Peptize soot and products of fuel oxidant; increase filter life |
| Metal deactivators | Chelating agents | Inhibit gum formation |
| Rust and corrosion inhibitors | Amines, amine carboxylates, and carboxylic acids | Prevent rust and corrosion in pipelines and fuel systems |
| Cetane improvers | Nitrate esters | Increase cetane number |
| Flow improvers | Polymers, wax crystal | Reduce pour point modifiers |
| Antismoke additions or smoke suppressants | Organic barium compounds | Reduce exhaust smoke |
| Oxidation inhibitors | Low–molecular weight amines | Minimize deposits in filters and injectors |
| Biocides | Boron compounds | Inhibit growth of bacteria and microorganisms |

**Alternative fuels for SI and CI engines:-**

There are three types of fuels viz. solid, liquid and gaseous fuels. Mainly liquid fuels are used in ic engines. Nowadays gaseous fuels such as LPG and CNG are also in use as automobile fuels. In early periods even solid fuels like charcoal, coal and slurry were also tried.

**Solid fuels:-**

They are not used nowadays, but when Rudolf was designing the engine he used coal dust mixed with water. He used very fine coal particles thoroughly mixed with water and injected in the engine. As coal is abundantly available it becomes an attractive fuel, but there are problems in using it. Major problems are abrasiveness due to solid particles which leads to wear of injectors and the piston rings.

**Liquid fuels:-**

Liquid fuels are preferred due to their high calorific value and they can be easily stored. Moreover the problem of wear is also overcome by using liquid fuels. The most common liquid alternative is alcohol. Alcohol has both advantages and disadvantages as a fuel which is discussed below.

**Advantages:-**

- It can be manufactured and even obtained from natural sources.
- It has a high octane number even greater than 100, so a large compression ratio can be employed.
- It has higher flame speed.
- Overall emissions produced by alcohol are less than gasoline.
- It provides higher pressure and more power in the expansion stroke.
- Sulphur content is less in alcohols.

**Disadvantages:-**

The calorific value of alcohol is very less, almost half of the general fuels used in ic engines. That means the fuel quantity required to produce a certain amount of power is doubled if we use alcohol, which inturn means that a vehicle can travel only half the distance with full fuel tank as it would have travelled if gasoline was used.

It is more corrosive than gasoline on metal and plastic parts. So use of alcohol puts restrictions on the design of the engine. All the parts like piston rings gaskets, etc. get worn out by long term alcohol use.

- Its combustion produces aldehydes in the exhaust which is not acceptable.
- They have poor ignition characteristics in general.
- Its use leads to poor starting characteristics in cold weather.
- Air can enter the storage tank due to low vapor pressure of alcohol and can form combustible mixture.
- Mainly methanol and ethanol are used as fuel in IC engines.

**Gaseous fuels:-**

Since physical delay is almost zero for gaseous fuels, they are suited for use in IC engines. Since the gas displaces the equal amount of air, the volumetric efficiency of the engine decreases. The major gaseous fuels are as follows:-

**Hydrogen :-**

Advantages of hydrogen:-

- Since there is no carbon in the fuel so the emissions are devoid of CO or HC. The exhaust mainly consists of H2O, N2 and NOx.
- It is easily available. It can be manufactured by a number of ways including electrolysis of water.
- If incase it is leaked to environment, it doesn't act as a pollutant.
- It has high energy content per unit volume. So for a given tank size, a larger distance can be traversed.
- Disadvantages of hydrogen as a fuel:-
- It is difficult to refuel and the possibility of knocking is more.
- The volumetric efficiency decreases by the use of hydrogen as a fuel.
- The flame temperature is very high so the NOx emissions increase.
- Its operation is costlier than gasoline.
- It has a lot of storage problems. In liquid state, it requires a thermally insulated fuel tank. In gas phase, it will require high pressure vessel with limited capacity.

Hydrogen can be used in diesel engines in 2 ways:-

By using in a dual fuel mode, in which hydrogen is inducted along with air and then the mixture of air and hydrogen is compressed in the cylinder. At the end of the compression stroke diesel is injected and the combustible mixture is burned. But hydrogen should be put in certain limits as it can lead to high pressure rise.

By surface ignition. Hydrogen is sprayed at the end of the compression stroke directly inside the cylinder. But the self ignition temperature of hydrogen is high, so it is sprayed on the hot glow plug in the combustion chamber which leads to the burning of hydrogen. This is known as surface ignition.

Hydrogen is a very reactive fuel, so a lot of care is to be taken in handling it. A flame arrester should be used to stop any possible back flash to the storage tank from the engine cylinder.

**Natural gas:-**

Natural gas is very easily available and is present at a number of locations. It can be easily obtained by process of drilling wells. When natural gas is obtained from drilling wells, it is known as casing head gas. It is generally treated for obtaining gasoline. When gasoline is taken out from natural gas, it is known as dry gas. Natural gas mainly consists of methane (60-95%) and other hydrocarbons. It also contains various amounts of N2, CO2, He and traces of other gases. When sulphur content is low, it is called sweet or else sour. It can be stored in two ways that is as compressed natural gas (CNG) and liquefied natural gas (LNG). In CNG, pressure of 16-25 bar is maintained and in LNG 70 to 210 bar at a temperature around -160oc. Now the advantages and disadvantages of the natural gas are discussed below.

Advantages of natural gas:-

- Octane number of natural gas is very high about 110. So, it has a very high flame speed and thus provides a higher compression ratio.
- Emissions are comparatively less. The aldehyde content in the emission is considerably less than methanol.
- Natural gas is abundantly available in the world.

Disadvantages of natural gas as fuel:-

- Volumetric efficiency of the engine decreases as it is a gaseous flow so the amount of air intake by the engine decreases.
- Energy density is low which leads to low engine performance.
- Fuel properties are inconsistent.
- Refueling is a slow process.
- Large pressurized fuel tank is required for its storage.
- Methane is used with diesel in CI engine. Methane becomes the major component (90% of methane in the mixture). Methane is introduced in the engine cylinder with the help of pressurized pipes.

Compressed natural gas (CNG) is nowadays commonly used in big cities like Delhi, where the emissions from automobiles have crossed the limits as the emissions from burning of CNG are considerably less as compared to the emissions produced by a gasoline engine. CO emission is almost nullified by the use of CNG.

**Liquefied petroleum gas:-**

Propane and butane are mainly used as LPG. Both are obtained from the drilling well process. Sometimes they are used alone and sometimes combination of the two is used in the engine. These gases are compressed and cooled and stored under pressure in tanks in liquid form which are sealed.