Module 6

# FUELS AND COMBUSTION

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**Q1) Define Fuel and give its classification.**

Ans) A fuel is a combustible substance containing carbon as the main constituent which on proper burning gives large amount of heat which can be used economically for domestic and industrial purpose.

**Classification of Fuels:**

Fuels
- Primary or Natural
  - Solid
    Eg) Wood, Peat, Lignite
  - Liquid
    Eg) Crude Petroleum
  - Gaseous
    Eg) Natural Gas
- Secondary or Derived
  - Solid
    Eg) Coke, Charcoal, Briquette coal
  - Liquid
    Eg) Kerosene, Diesel, Petrol
  - Gaseous
    Eg) LPG, Water gas, Biogas

**Q2) What are the characteristics of an ideal Fuel.**

Ans) A good fuel should have the following characteristics:

**1) Calorific Value:** A good fuel should have high calorific value since the amount of heat liberated and temperature attained thereby depends upon the calorific value of fuel.

**2) Low Moisture Content:** The moisture content of the fuel should be low, because moisture reduces the heating value (calorific value) of fuel.

**3) Moderate Ignition Temperature:** A good fuel should have moderate ignition temperature. Low ignition temperature is dangerous for storage and transport of fuel, since it can cause fire hazards. On the other hand high ignition temperature causes difficulty in initiating a fire.

**4) Low Non-Combustible matter:** Higher the noncombustible matters lower will be the calorific value and it also causes disposal problems.

**5) Moderate velocity of combustion:** Fuel should have a moderate rate of combustion. If the rate of combustion is low, then the required temperature is not attained and high rate of combustion is not desirable.

**6) Easy to transport:** Fuel must be easy to handle, store and transport at a low cost. Transportation of gaseous fuel is costly and can cause fire hazards. Storage cost of fuel in bulk should be low.

**7) Products of combustion:** A good fuel should not release harmful combustion products like CO, SO2, NO, H2S etc which have harmful effects on health of living beings. Therefore a good fuel should be environmentally friendly.

**Q3) Define the following terms:**

Ans)1) **Calorific Value:** The total quantity of heat liberated when a unit mass of the fuel is burnt completely.

**Units:** Solid and Liquids - Cals/gm or Kcal/kg

Gases - $Kcal/m^3$

**2) Ignition Temperature:** The minimum temperature to which a substance must be heated before it burns spontaneously independently of the source of heat.

**3) Calorie:** A Calorie is defined as the amount of heat required to raise the temperature of one gram of water through $1^0$c ie from $15.5^0$c to $16.5\ ^0$c

**4) Kilocalorie:** A kilocalorie is defined as the amount of heat required to raise the temperature of one kilogram of water through $1^0$c ie from $15.5^0$c to $16.5\ ^0$c . 1Kcal= 1000Cal

**Q4) What is Dulong's Formula.**

Ans) The calorific value of a fuel can be calculated approximately from the ultimate analysis, which gives the % of elements like C, H, S, N and O.

According to Dulong, the calorific value of fuel is the sum of calorific values of all the elements present. The calorific values of different elements are given as under,

Calorific value of Carbon= 8080cal/gm

Calorific value of Sulphur = 2240 cal/gm

Thus, Dulong's formula is given as,

$$\boxed{\textbf{H.C.V} = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]}$$

where C,H,O and S are the % of C,H,O and S respectively.

In this formula, oxygen is assumed to be present in combination with hydrogen as water .

**Q5) Define Gross Calorific Value (G.C.V) or Higher Calorific Value (H.C.V) and Net Calorific value (N.C.V) or Lower Calorific value (L.C.V)**

Ans ) **Gross Calorific Value( G.C.V):** The total amount of heat produced when a unit mass of fuel is burnt completely and the products of combustion are cooled down to room temperature usually $60^0$F or $15^0$c.

**Net Calorific value (N.C.V):** It is defined as the net amount of heat produced when a unit mass of fuel is burnt completely and the products of combustion are allowed to escape into the atmosphere.

Net Calorific Value = Gross Calorific Value – Latent heat of water vapour produced.

= G.C.V – Mass of Hydrogen per unit weight of fuel burnt x 9 x Latent heat of Steam

$= \text{G.C.V} - \frac{H}{100} \times 9 \times 587$

$$\boxed{\textbf{N.C.V} = \textbf{G.C.V} - 0.09H \times 587}$$

# SOLID FUELS

**Q6) Explain in brief the various tests under proximate analysis of coal.**

Ans) **Proximate Analysis:** This includes the determination of moisture, volatile matter, ash and fixed carbon. It gives valuable information regarding commercial classification and determination of suitability for a particular industrial use.

**1) % Moisture:** A known quantity of air dried coal sample is taken in a crucible and heated in an oven at 105°c to 110°c for 1 hour. Then the coal sample is taken out from the oven, cooled in a desiccator and weighed .The heating and cooling procedure is continued till constant weight.

$$\textbf{\% Moisture} = \frac{\textbf{Loss in weight of coal x 100}}{\textbf{Weight of coal taken}}$$

**Significance:** Higher the moisture content, lower will be the calorific value and vice versa. Thus it reduces the efficiency of fuel and increases the transport cost.

**2) % Volatile matter:** A known quantity of moisture free coal sample is taken in a crucible with vented lid and kept in a muffle furnace maintained at 925+-20 °c for exactly 7 minutes. After that it is removed, cooled in a desiccator and weighed.

$$\textbf{\% Volatile matter} = \frac{\textbf{Loss in weight of Volatile matter x 100}}{\textbf{Weight of coal taken}}$$

**Significance:**

a) High volatile matter.

b) Gives long smoky flame.

c) Escapes into the atmosphere and therefore decreases the calorific value.

d) Decreases the quality and hence affects the rank of coal.

**3) Ash Content:** A known quantity of sample after determination of volatile matter is taken in an open silica crucible and heated at 700°c to 750°c in a muffle furnace until a constant weight is obtained .The weight of the residue is reported as Ash.

$$\textbf{\% Ash} = \frac{\textbf{Weight of residue x 100}}{\textbf{Weight of coal taken}}$$

**Significance:**

1) Higher the ash content more will be the non-combustible matter and lower will be the calorific value.
2) Increases disposal problems.
3) The presence of ash increases transporting, handling and storage cost.
4) It also causes early wear of furnace walls, burning of apparatus.

**4) % Fixed Carbon:** This can be determined as follows,

% Fixed Carbon = 100-(% Moisture + % Volatile Matter + % Ash)

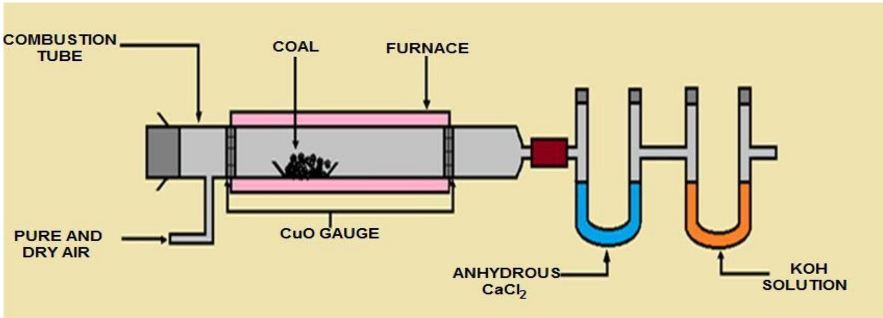
**Significance:**

1) Higher the % fixed carbon, more will be the calorific value.

2) A good quality coal should have low moisture content, low volatile matter and low ash content which automatically leads to high % fixed carbon.

**Q7) How is Ultimate analysis is carried out? What is its significance?**

Ans) It involves following determination,




**1) % Carbon and % Hydrogen:**

About 1-2gm of accurately weighed coal sample is burnt in a current of oxygen in a combustion apparatus, when C and H present in coal are oxidized to $CO_2$ and $H_2O$ respectively. The gaseous products are absorbed respectively in KOH and $CaCl_2$ tubes of known weights .The increase in weights of these are determined.

**Reactions:**

$$2KOH + CO_2 \longrightarrow K_2CO_3 + H_2O$$

$$CaCl_2 + 7\,H_2O \longrightarrow CaCl_2.7\,H_2O$$

$$\underset{12}{C} + \underset{32}{O_2} \longrightarrow \underset{44}{CO_2} \quad , \quad \underset{2}{H_2} + \underset{16}{1/2O_2} \longrightarrow \underset{18}{H_2O}$$

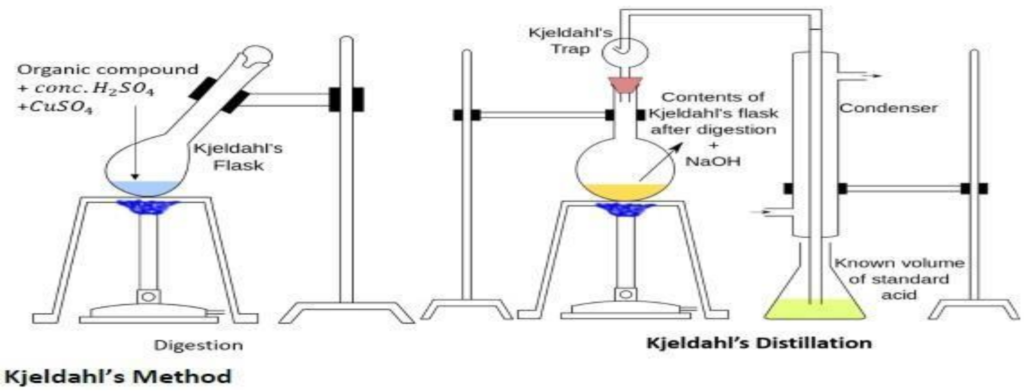
$$\textbf{\% Carbon} = \frac{\textbf{Increase in weight of KOH tube x 12 x 100}}{\textbf{Weight of coal sample x 44}}$$

$$\textbf{\% Hydrogen} = \frac{\textbf{Increase in weight of } CaCl_2 \textbf{ tube x 2 x 100}}{\textbf{Weight of coal sample x 18}}$$

**Significance:** 1) Higher the percentage of Carbon and Hydrogen, higher is the calorific value and better is the quality of coal.

**2)** Hydrogen is mostly associated with volatile matter and present in the form of water. Hence, higher content of Hydrogen is undesirable.

**2) % Nitrogen:**




- About 1gm of accurately weighed coal sample is digested in a Kjeldahl's flask with conc $H_2SO_4$, $K_2SO_4$ and $HgSO_4$ (acts as a catalyst) .The nitrogen present in the coal gets converted into ammonium sulphate. The contents of the Kjeldahl's flask are quantitatively transferred to a round bottomed flask, then NaOH is added and refluxed.
- Liberated ammonia is collected in a flask containing known quantity of known normal $H_2SO_4$. The unreacted $H_2SO_4$ is titrated against std NaOH using phenolphthalein indicator till the colour changes from colourless to light pink. A blank titration of the same $H_2SO_4$ is carried out.

$$\textbf{\% Nitrogen} = \frac{\textbf{Volume of acid used x Normality of acid x 1.4}}{\textbf{Weight of coal sample taken}}$$

$$(NH_4)_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2\,NH_3 + 2H_2O$$

Let weight of coal taken = W gms

Volume of N/10 NaOH required for Blank reading = Y ml

Volume of N/10 NaOH required = x ml (to titrate unreacted acid)

Volume of N/10 acid reacted with ammonia = (y-x)ml

olume of N/10 ammonia = (y-x) ml

1000ml of 1N ammonia solution = 17gm of $NH_3$

1000ml of 1 N $NH_3$ solution = 14gm of Nitrogen

1000ml of 0. 1 N $NH_3$ solution = 1.4gm of Nitrogen

(y-x) ml of 0.1N $NH_3$ solution = $\frac{1.4\,(y-x)}{1000}$ gms of Nitrogen

W gm of coal contains $\frac{1.4\,(y-x)}{1000}$ gms of Nitrogen

100gm of coal contains = $\frac{1.4(y-x)}{1000} \times \frac{100}{W}$ gm of Nitrogen

% Nitrogen = $\frac{1.4\,(y-x)}{10 \times W}$

OR **% Nitrogen** = $\mathbf{\frac{\text{Volume of acid used x Normality of acid x 1.4}}{\text{Weight of coal sample taken}}}$

**Significance:**

Since, Nitrogen is an inert and incombustible gas; it doesn't help in combustion and thus has no calorific value. Hence its presence is undesirable in good quality coal.

**3) % Sulphur:** A known weight of coal is burnt completely in Bomb calorimeter, in a current of oxygen .During burning, sulphur present in coal is oxidized to sulphate. Ash from bomb calorimeter is extracted with dil HCl and acid extract is treated with Barium Chloride solution to precipitate sulphate as Barium Sulphate. This precipitate is filtered , washed and heated to a constant weight and weighed.

$$\underset{32}{S} \xrightarrow{O2} SO_4 \xrightarrow{BaCl2} \underset{233}{BaSO_4}$$

$$\boxed{\textbf{\% Sulphur} = \frac{\text{Weight of } BaSO_4 \text{ obtained x 32 x 100}}{\text{Weight of coal sample x 233 taken in bomb}}}$$

**Significance:** Presence of Sulphur in coal contributes to the calorific value of coal ,but its combustion products,$SO_2$ and $SO_3$ are highly corrosive to the equipment's specially in presence of moisture.

Also ,the oxides of sulphur cause environmental pollution.

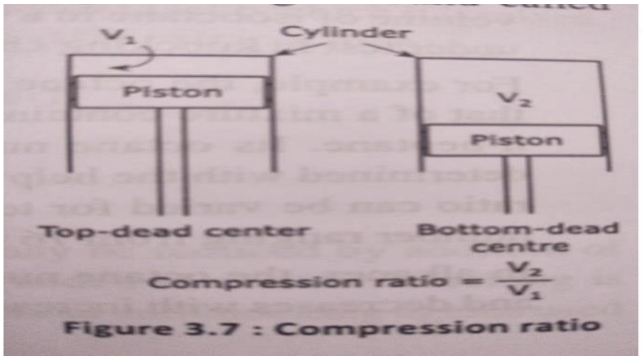
**4) % Ash:** Same as in Proximate Analysis

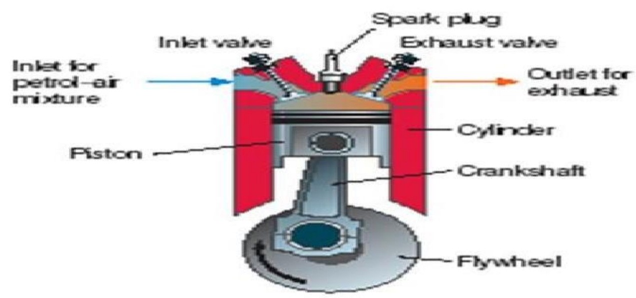
**5) % Oxygen** = 100 - ( % C + % H + % N + % S + % Ash)

# Liquid Fuels

**Q8) Explain knocking in Petrol engine.**

Ans) **Knocking:** It is defined as sharp metallic sound produced in the internal combustion engine and results into a loss of energy.



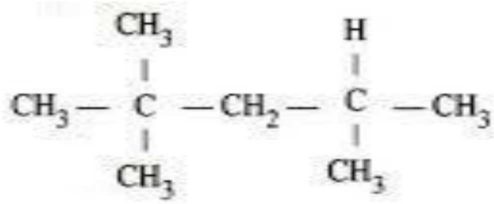

**Petrol Engine:**

- The petrol engine is a spark ignition type of internal combustion engine.
- In this a mixture of air and fuel (petrol) is compressed and ignited by an electric spark.
- Generally, this combustion of fuel proceeds in a regular and uniform way. But in certain circumstances, the rate of oxidation is so great that the mixture detonates producing the sound called **"Engine Knock'.**
- The rate of oxidation of a hydrocarbon molecule depends on the number of carbon atoms in the molecule, structure and temperature.
- The temperature in turn depends upon the compression ratio.
- The ratio of the cylinder volume at the end of the suction stroke to that at the end of the compression stroke of the piston. Theoretically the power output and efficiency of an IC engine should increase with the increase in the compression ratio (CR).But in actual practice, the power increases to a maximum and then falls rapidly with further increase in CR, knocking becomes more pronounced and heavy as the CR is increased above the optimum value and finally pre-ignition occurs.
- The tendency to knock depends upon the type of fuel, engine design, plug location etc.

**Q 9) Define and Explain Octane Number.**

Ans) The knocking characteristics of petrol sample are described by the octane number or antiknock value. Higher the octane number , lower is the tendency to knock and better is the quality of petrol.

- Isooctane (2,2,4-trimethyl pentane) has the least knocking tendency and its octane number is arbitrarily fixed as 100.
- n-Heptane ,a straight chain hydrocarbon, has highest tendency to knock and is assigned an octane number zero. In general, straight chain hydrocarbons have low octane numbers and those with branched chain have high values. The petrol whose octane number is to be determined is compared with reference mixtures of isooctane and n-heptane.
- **Octane Number is defined** as the percentage by volume of Iso-Octane in a mixture of Iso-octane and n-heptane which has the same knocking characteristics as that of fuel under test.



Iso octane 2, 2, 4-trimethyl pentane
Octane number = 100

n-Heptane
Octane number = 0

- For example, the octane number of automobile petrol is found to be equivalent to that of a mixture containing 70% by volume of Isooctane and 30% by volume of n-heptane. Its octane number is said to be 70.
- The octane number of petrol is determined with the help of a special single cylinder engine where the compression ratio can be varied for testing the octane. Automobiles petrol have octane number ranging from 76 to 95.
- In alkanes, the octane number increases with the number of branches in the chain and decreases with increase in chain length. Alkenes have higher octane number than alkanes containing same number of carbon atoms.
- Among alkenes, the octane number increases with a shift in the position of double bond to the center of the molecules.
- Cycloalkanes have a higher octane rating than alkanes with the same number of carbon atoms. The highest octane numbers are associated with the aromatic hydrocarbons.
  The octane number of some common hydrocarbons is given below

| **Hydrocarbon** | **Octane number** |
|---|---|
| Benzene | 100+ |
| Isopentane | 90 |
| Cyclopentane | 77 |
| 2-methyl pentane | 71 |
| n-pentane | 62 |
| n-hexane | 26 |

- Fuels with octane number greater than 100 are quite common now-a-days. They are rated by comparison with a blend of iso-octane with Tetra Ethyl Lead ( TEL) which greatly diminishes the knocking tendency of any hydrocarbon with which it is mixed. The value of octane number in such cases is determined by extrapolation.

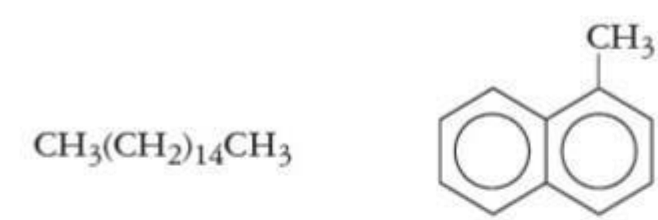
**Q10) Explain knocking in Diesel Engines.**

Ans) The diesel engine is a compression ignition engine that uses long straight chain hydrocarbons having boiling range $180^0$c to $360^0$c.

- Here air is passed into the cylinder and compressed to about 500psi (upstroke).
- Due to compression, the temperature of air rises to about $500^0$c.
- The diesel oil is injected towards the end of compression stroke in the form of fine droplets into the hot compressed air.
- The injected oil droplets absorb the heat from the compressed air and get vaporized, attain self-ignition temperature and burn spontaneously during the downward stroke.
- However the combustion of fuel in the diesel engines is not instantaneous but there exists a time lag between fuel injection and ignition.
- This time lag or ignition delay is a measure of knocking in diesel fuels.
- If the fuel has a short ignition delay, the fuel injected into the burning mixture continues to burn at the rate at which it is injected.
- On the other hand , if the fuel has a long ignition delay, then the fuel accumulation occurs in the engine even before ignition.
- When ignited, an explosive combustion occurs with sudden increase in pressure.
- This is called **'Diesel Knock'.**
- Longer the ignition delay, greater is the diesel knock.

**Q11) Explain Cetane Number**.

- The knocking characteristics of a diesel oil are expressed in terms of cetane number. Cetane (C16H34) is a saturated hydrocarbon, ignites very quickly and thus has very short ignition delay.
- Its Cetane number is 100. On the contrary α- methyl napthalene has very long ignition
- delay as compared to any other diesel fuel. Hence its Cetane Number is zero.
- **Defination:** The percentage by volume of cetane in a mixture of Cetane and α- methy
- napthalene which just matches the knocking characteristics of diesel oil under test.
- Oils having high octane no are good diesel fuels (least ignition delay) but are poor gasoline fuels (have low octane no) and vice versa.
- The Cetane no of diesel oil can be increased by addition of certain compounds called Dopes or Ignition accelerators like ethyl nitrite ($C_2H_5NO_2$) ,ethyl nitrate ($C_2H_5NO_3$), Isoamyl nitrate ($(CH_3)_2CHCH_2CH_2NO_3$) etc



*n*-Hexadecane (cetane) Cetane number = 100

α-Methylnaphthalene Cetane number = 0

**Q12) Write a short note on Anti-knocking agent.**

Ans) The octane number of many poor fuels can be raised by the addition of Tetra Ethyl Lead(TEL)or (C2H5)4Pb or diethyl telluride (C2H5)2Te. About 0.5ml of TEL is added to 1 litre of motor fuel and 1ml of TEL is added to 1 litre of aviation fuel.

- Knocking in a petrol engine is due to the spontaneous ignition of the last portion of compressed mixture of petrol and air .The process of preignition is due to the production of hydroxyl and other free radicals which lead to explosive combustion .Addition of TEL react with free radicals and lead oxide is produced which decreases the chances of early denotation.
- The deposit of lead oxide is harmful to engine life. Therefore, ethylene dibromide (C 2H4Br2) is added to dope to convert the lead formed by the combustion into more volatile lead bromide which is swept out with the exhaust gases.
- But this also leads to atmospheric pollution allowed to settle down and the lower glycerine layer is drawn off. The upper layer of the methyl esters is washed and purified further. The unreacted methanol is recovered in a condenser, purified in a rectifying column and recycled.

**Q13) Write a short note on Unleaded Gasoline and Catalytic Converter.**

Ans) **Unleaded Gasoline:**

- Mixing 0.1% TEL per gallon of gasoline increases the octane rating by 10 to 15 points. Since lead is toxic and causes environmental pollution, slowly it has been phased out from gasoline.
- Unleaded gasoline is supplied in India to minimize undesirable lead emissions on one hand and to enable incorporation of catalytic converters with the internal combustion engines.
- Catalytic converter is fitted in the exhaust system after the exhaust manifold of petrol driven/vehicles.

**Catalytic Converter:**

When the exhaust gases containing partially oxidized carbon, unoxidized hydrocarbons, and $NO_x$ come into contact with the coated catalyst surface, they get catalytically converted into $CO_2$ and $H_2O$. Under suitable conditions of engine operation $NO_x$ come gets reduced to $N_2$.

- $CO + 0.5O_2 \rightarrow CO_2$
- $C_3H_6 + 4.5O_2 \rightarrow 3CO_2 + 3H_2O$
- $NO + CO \rightarrow N_2 + CO_2$

- Catalysts made of noble metals like Platinum (Pt) and Palladium (Pd) are susceptible to get poisoned by lead and they are very expensive.
- Hence leaded petrol cannot be used in engines with catalytic converters. The newly developed

catalytic converter technology consists of a ceramic or metallic honeycomb support coated with a low cost catalyst placed in a suitably designed non- corrosive metallic housing.

**Q14) Write a short note on oxygenates (MTBE).**

**Ans**) Oxygenates are the fuel molecules which contain one or more oxygen atoms. For eg. Methanol, Ethanol, Methyl tertiary butyl ether (MTBE), Ethyl tertiary butyl ether (ETBE).

- MTBE is a blending component of gasoline, used as an oxygenate to raise the octane number and to replace tetraethyllead (TEL).
- All these four oxygenates have octane ratings substantially higher than 100. MTBE is produced by a simple reaction of isobutylene with methanol.
- Tertiary amyl methyl ether (TAME) is a higher analog of MTBE. It is produced by the additive reaction of tertiary amylenes with methanol in presence of acidic reaction promoters. TAME has lower octane number and higher boiling point than MTBE. It is also compatible with gasoline hydrocarbons blends.

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