

UNIT –IV

FUELS AND COMBUSTION

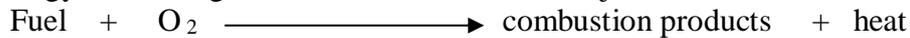
TOPICS TO BE COVERED

Fuels: Introduction – Classification of fuels – Coal - Analysis of coal (proximate and ultimate) – Carbonization – Manufacture of metallurgical coke (Otto Hoffmann method) – Petroleum – Manufacture of synthetic petrol (Bergius process) – knocking – Octane Number – Diesel Oil – Cetane Number – Natural Gas – Compressed Natural Gas (CNG) – Liquefied Petroleum Gases (LPG) – Power Alcohol and Biodiesel. **Combustion of**

Fuels: Introduction – Calorific Value – Higher and Lower Calorific Values – Theoretical calculation of Calorific Value – Ignition Temperature – Spontaneous Ignition Temperature – Explosive Range – Flue Gas Analysis (ORSAT Method).

Fuel

Fuel is a combustible substance containing carbon as major constituent, which gives out heat energy on burning. It contains carbon as the major constituent.

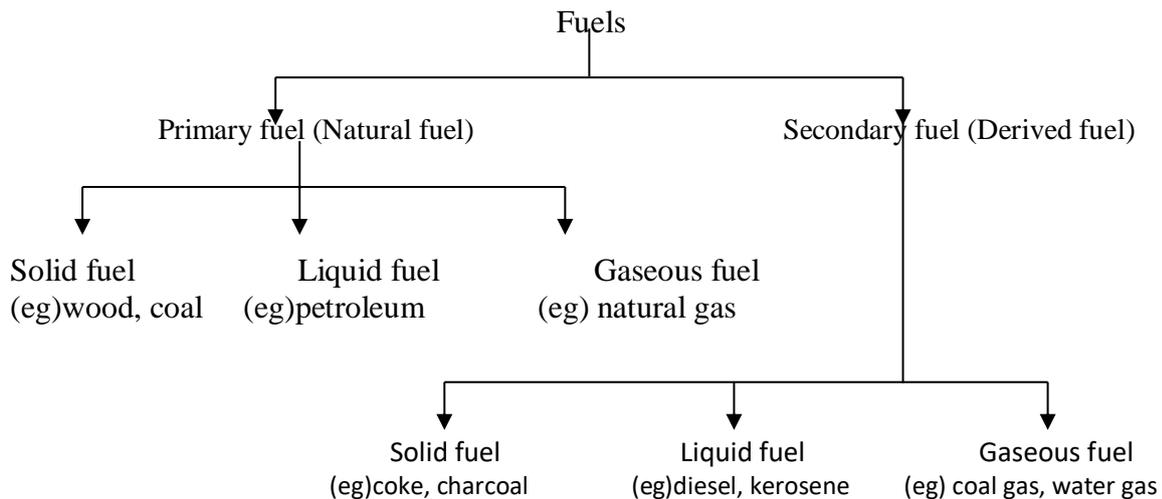


Characteristics of a good fuel:

A good fuel should have,

1. High calorific value.
2. Moderate ignition temperature and velocity of combustion.
3. Low moisture content, non-combustible matter.
4. Low cost.
5. The products of combustion must be harmless.
6. Easy to transport.
7. Combustion must be easily controllable.
8. Must not burn with much smoke.

Classification of fuels



Coal (Solid fuel)

- Coal is a highly carbonaceous matter that is formed as a result of alteration of vegetable matter under favorable conditions.
- It consists of C, H, N, O & non-combustible inorganic matter.

Coalification or Metamorphism:

The process of alteration of vegetable matter into coal is called coalification.

Classification of coal (Varieties of coal)

(Moisture, volatile, H, O, N, S contents decreases)

Wood → Peat → Lignite → Bituminous coal → Anthracite

—————→
(Hardness, calorific value, carbon content increases)

Analysis of coal

To assess the quality of coal, two types of analysis are made.

1. Proximate analysis
2. Ultimate analysis

Proximate analysis

It involves the determination of percentage of moisture content, volatile matter, ash content and fixed carbon in coal.

i) Moisture content

About 1g of powdered, air dried coal sample is taken in a crucible and heated to **100 - 105°C** in an **electric hot air oven** for **1 hour**. The loss in weight of the sample is found out and the percentage of moisture is calculated as,

$$\% \text{ of moisture} = \frac{\text{Loss in weight of coal}}{\text{Weight of coal taken}} \times 100$$

Significance of Moisture content

High percentage of moisture is undesirable because

- a) it reduces calorific value.
- b) it increases the transport cost.
- c) it consumes more heat.

ii. Volatile matter

After analyzing moisture content, the crucible with residual coal sample is covered with a lid and is heated to **950 ± 20° C** for **7 minutes** in an electric furnace. The loss in weight of the sample is found out and the percentage of volatile matter is calculated as,

$$\% \text{ of volatile matter} = \frac{\text{Loss in weight of coal}}{\text{Weight of coal taken}} \times 100$$

Significance of volatile matter

High percentage of volatile matter is undesirable because

- a) It reduces calorific value.

- b) It burns with long smoky flame.
- c) It does not coke well.

iii. Ash content

After analyzing volatile matter, the crucible with residual coal sample is heated without lid at $700 \pm 50^\circ \text{C}$ for **30 minutes** in an electric furnace. The weight of ash is found out and the percentage of ash content is calculated.

$$\% \text{ of ash} = \frac{\text{Weight of ash formed}}{\text{Weight of coal taken}} \times 100$$

Significance of Ash content

High percentage of ash content is undesirable because

- a) it reduces calorific value.
- b) it causes hindrance to heat flow.
- c) It produces clinkers that block air supply.
- d) It increases transport, handling, storage and disposal cost.

iv. Fixed carbon

It is determined by subtracting the sum of moisture, volatile matter and ash contents from 100.

$$\% \text{ of fixed carbon} = 100 - \% \text{ of (moisture + volatile matter + ash)}$$

Significance of Fixed carbon

High percentage of fixed carbon is desirable because

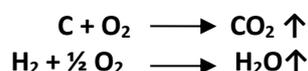
- a) It increases calorific value.
- b) It helps in designing the furnace and shape of fire box.

Ultimate analysis

It involves the determination of percentage of carbon, hydrogen, nitrogen, sulphur, ash content and oxygen in coal.

i) Carbon and hydrogen

- A known amount of coal sample is burnt in a current of oxygen in a combustion apparatus.
- Carbon and hydrogen present in the coal sample is converted into CO_2 and H_2O .



- The liberated CO_2 and H_2O vapours are absorbed by KOH and anhydrous CaCl_2 tubes of known weights.
- The increase in weight of KOH tube is due to the absorption of CO_2 .
- The increase in weight of CaCl_2 tube is due to the absorption of H_2O .
- From the increase in weights of KOH & CaCl_2 tubes the percentage of carbon and hydrogen present in the coal can be calculated as,

$$\% \text{ of carbon in coal} = \frac{\text{Increase in weight of KOH tube}}{\text{Weight of coal sample}} \times \frac{12}{44} \times 100$$

$$\% \text{ of hydrogen in coal} = \frac{\text{Increase in weight of CaCl}_2 \text{ tube}}{\text{Weight of coal sample}} \times \frac{2}{18} \times 100$$

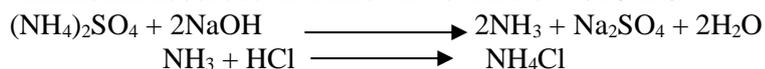
ii) Nitrogen

Determination nitrogen content is carried out by Kjeldahl's method.

- A known amount of powdered coal sample is heated with conc. H₂SO₄ in a long necked flask.
- Nitrogen in the coal is converted into Ammonium sulphate (clear solution).



- The clear solution is then heated with excess of NaOH and the liberated ammonia absorbed in a known volume of N/10 HCl.



- The volume of unused N/10 HCl is then determined by titrating against std. NaOH.
- Thus the amount of acid neutralized by liberated ammonia from coal is determined.
- From this the percentage of nitrogen is calculated as,

$$\% \text{ of nitrogen in coal} = \frac{1.4 \times \text{volume of acid consumed} \times \text{Normality}}{\text{Weight of coal sample}}$$

iii) Sulphur

- A known amount of coal sample is burnt in a bomb calorimeter.
- During this process, sulphur is converted to sulphate which is extracted with water.
- The extract is then treated with BaCl₂ solution so that the sulphates are precipitated as BaSO₄.
- The precipitate is filtered, dried and weighed.
- From the weight of BaSO₄, sulphur present in the coal is calculated as,

$$\% \text{ of sulphur in coal} = \frac{\text{Weight of BaSO}_4}{\text{Weight of coal sample}} \times \frac{32}{233} \times 100$$

iv) Ash content

A known weight of coal sample is heated without lid at 700 ± 50° C for 30 minutes in an electric furnace. The loss in weight of the sample is found out and the percentage of ash content is calculated.

$$\% \text{ of ash} = \frac{\text{Weight of ash formed}}{\text{Weight of air dried coal}} \times 100$$

v) Oxygen

The percentage of oxygen is calculated as,

$$\% \text{ of oxygen in coal} = 100 - \% \text{ of (C + H + N + S + ash)}$$

Significance of ultimate analysis

1. Higher the percentage of carbon and hydrogen, better the quality and greater is its calorific value.
2. Presence of nitrogen in coal is undesirable.

3. Presence of sulphur in coal is undesirable because SO_2 and SO_3 are harmful and corrodes the equipment.
4. Presence of oxygen in coal is undesirable because it increases the moisture holding capacity.

Carbonization

The process of strong heating of coal in the absence of air & converting it into coke is known as carbonization of coal.

Coke

Lustrous, dense, porous and coherent mass obtained by strong heating of coal in the absence of air is called coke.

Types of carbonization

- a) **Low-temperature carbonization - heating coal at 500 – 700⁰C.**
- b) **High-temperature carbonization - heating coal at 900 – 1200⁰C.**

Differences between Low-temperature carbonization & High-temperature carbonization

| Low-temperature carbonization | High-temperature carbonization |
|--|---|
| 1. Heating coal at 500 – 700 ⁰ C. | Heating coal at 900 – 1200 ⁰ C |
| 2. Yield of coke is 75-80% | Yield of coke is 65-75% |
| 3. The coke is used for domestic purpose. | The coke is used for metallurgical purpose. |
| 4. Soft coke is obtained. | Hard coke is obtained. |
| 5. No smoke is produced. | Smoke is produced. |

Metallurgical coke

When bituminous coal is heated strongly in the absence of air the volatile matter escapes out and the mass becomes hard, strong, porous and coherent mass called metallurgical coke. This process of conversion of coal into coke is called **carbonization**.

When coal is heated strongly, the mass becomes soft, plastic and fuses to give a coherent mass, such type of coal is called **caking coal**.

But if the mass so produced is hard, porous and stronger, it is called **coking coal**.

Characteristics of metallurgical coke

Porosity

Coke should be highly porous so that oxygen will have intimate contact with carbon and the combustion will be complete and uniform.

Calorific value

Calorific value should be high.

Combustibility

The coke should burn easily.

Reactivity

Reactivity of coke should be low.

Cost

It should be cheap and readily available.

Manufacture of metallurgical coke

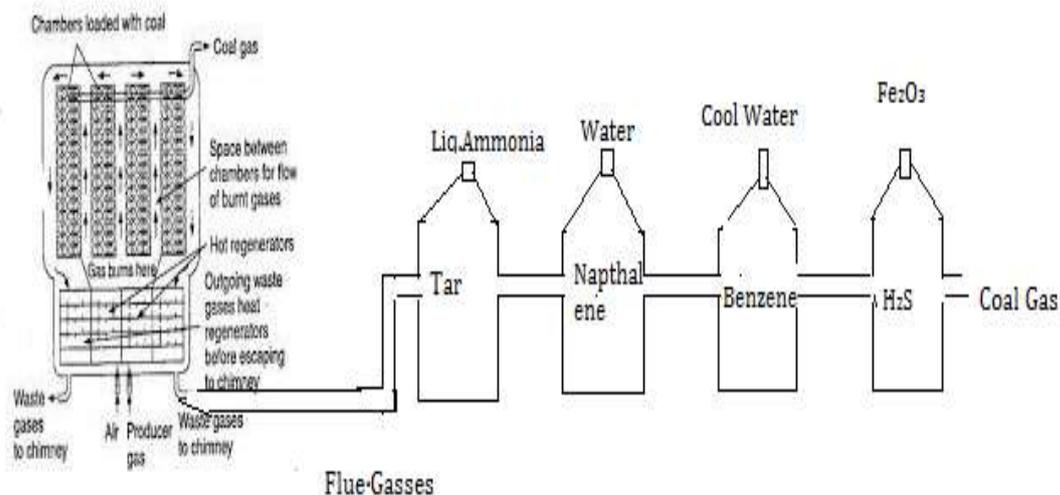
OTTO - HOFFMAN'S BY-PRODUCT OVEN METHOD

Otto – Hoffman designed the modern by-product oven in order to,

- Increase the thermal efficiency of the carbonization process.
- To recover the various by –products.
- Heating is done on the basis of ‘**regenerative system of heat economy**’ by using the waste flue gases for heating purpose.

Description of the oven

- The oven consists of number of silica chambers.
- The chambers are about 10 – 12 m long, 3 – 4 m height and 0.42 – 0.45 m wide.
- Each chamber is provided with a charging hole at the top, gas off take valve at the top end and iron door at each end for discharging coke.



Working

- **Coal** is introduced into the **silica chambers** and the chambers are closed.
- The chambers are heated to **1200°C** by burning of gaseous fuels (air and producer gas) by passing them through **2nd and 3rd** hot regenerators.
- **Hot flue gases** produced during carbonization come out through **1st and 4th** regenerators raising the temperature to 1000°C.
- The fuel gas is now passed through the **1st and 4th** regenerators (preheating).
- Flue gases come out through the **2nd and 3rd** regenerators raise the temperature to 1000°C. This cycle goes on. This process of reversing the direction of fuel & flue gases is known as ‘**regenerative system of heat economy**’.

- The time taken for the carbonization process is 11 to 18 hours.
- When the process is over, coke is removed from oven and cooled by dry quenching.

Recovery of by – Products:

The gas coming out from the oven is known as ‘coke oven gas’ consisting of ammonia, H₂S, Naphthalene, benzene, tar, moisture etc.

I. Recovery of Tar

- The gas is passed through a tower in which **liquor ammonia** is sprayed.
- Tar and dust gets dissolved and gets collected in a tank below.
- The tank is heated by steam coils to recover ammonia.

II. Recovery of Ammonia

- The gases from the chamber are then passed through another tower in which **water** is sprayed.
- Ammonia dissolves and gets collected as NH₄OH.

III. Recovery of Naphthalene

- The gases are again passed through a tower where **cold water** is sprayed. Here naphthalene gets condensed.

IV. Recovery of Benzene

- The gases are passed through another tower where **petroleum** is sprayed. Here benzene gets condensed.

V. Recovery of Hydrogen sulphide

- The remaining gases are then passed through a purifier packed with **moist Fe₂O₃**. Here H₂S is retained.

VI. Recovery of Coal gas

The final gas left out is called **coal gas** which is used as **fuel gas**.

Advantages

- Time taken for carbonization is 11 – 18 hrs.
- The yield of coke is 70%.
- Valuable by-products are obtained.

Petroleum (Liquid fuel)

Definition

Petroleum or crude oil is **dark greenish brown viscous liquid found deep in earth’s crust**. It is a mixture of various hydrocarbons.

Composition of Crude oil

| Constituents | Percentage (%) |
|--------------|------------------|
| C | 80- 87 |
| H | 11-15 |
| S | 0.1 – 3.5 |
| N + O | 0.1 – 0.5 |

Refining of Petroleum or crude oil

- The **crude oil** is a mixture of oil, water and unwanted impurities.

- The process of removing impurities and separating crude oil into various fractions is called as Refining of Petroleum.

Steps of refining

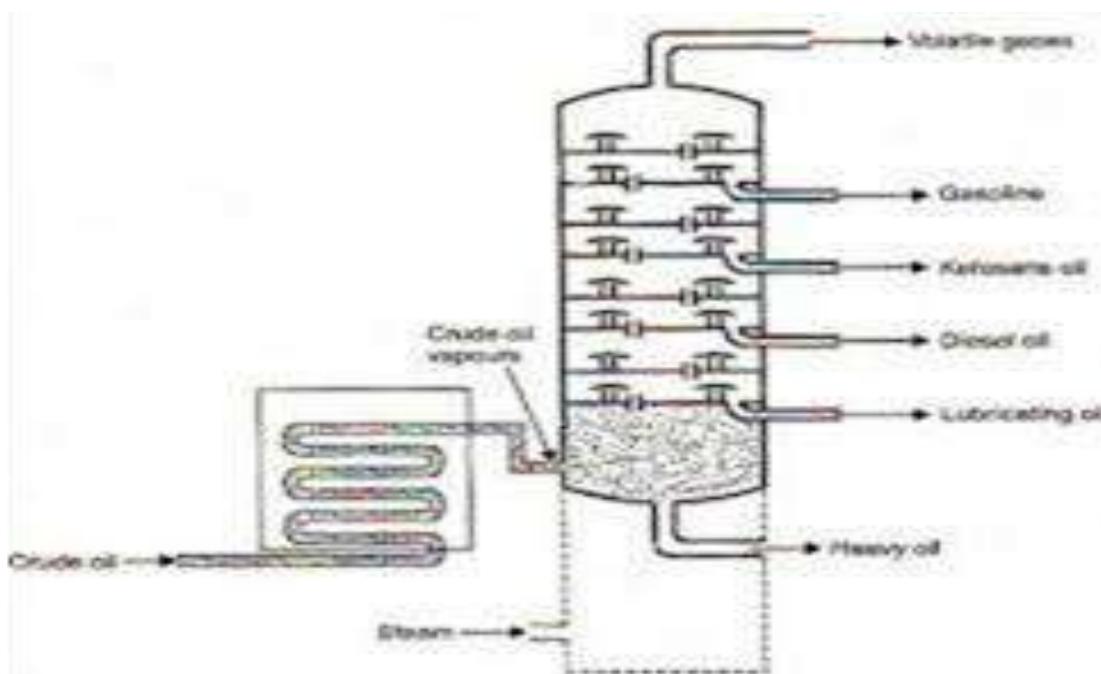
i) Separation of water (Cottrell's process)

The crude oil is an emulsion of oil and salt water. The crude oil is allowed to flow between two highly charged electrodes. Here the water droplets combine to form large drops which separate out from oil.

ii) Removal of sulphur compounds

Sulphur compounds are removed by treating crude oil with copper oxide. The copper sulphide formed is separated by filtration.

iii) Fractional distillation



- Purified crude oil is heated to 400°C in an iron retort. The oil gets vapourised. The hot vapours are passed up a 'fractionating column'.
- The fractionating column is a tall cylindrical tower containing a number of horizontal steel trays at short distances.
- As the vapours go up they become cooler and get condensed at different trays.
- The fractions having higher boiling points condense at lower trays and the fractions having lower boiling points condense at higher trays.

Various fractions obtained during fractional distillation

| No | Name of the fraction | Boiling point | Range of C atoms | Uses |
|----|----------------------|---------------|---------------------------------|--------------------|
| 1 | Uncondensed gases | Below 30°C | C ₁ – C ₄ | Fuel as LPG |
| 2 | Petroleum ether | 30 – 70 | C ₅ – C ₇ | As solvent |
| 3 | Gasoline or petrol | 40 – 120 | C ₅ – C ₉ | Fuel for IC engine |

| | | | | |
|---|---------------------------|-----------|-----------------------------------|---------------------------------|
| 4 | Naphtha or solvent spirit | 120 – 180 | C ₉ – C ₁₀ | Solvent in paints, dry cleaning |
| 5 | Kerosene | 180 – 250 | C ₁₀ – C ₁₆ | Fuel |
| 6 | Diesel | 250 - 320 | C ₁₅ – C ₁₈ | Diesel engine fuel |
| 7 | Heavy oil | 320 - 400 | C ₁₇ – C ₃₀ | Fuel for ship |

Fractions of heavy oil

| No | Name of the fraction | Uses |
|----|---------------------------|-----------------------------------|
| 1 | Lubricating oils | As lubricants. |
| 2 | Petroleum jelly(Vaseline) | Medicines and cosmetics. |
| 3 | Grease | As lubricant. |
| 4 | Paraffin wax | Used in candles, boot polishing. |
| 5 | Pitch | Making road, water proof roofing. |

Synthetic petrol (Synthetic liquid fuel)

Hydrogenation of coal

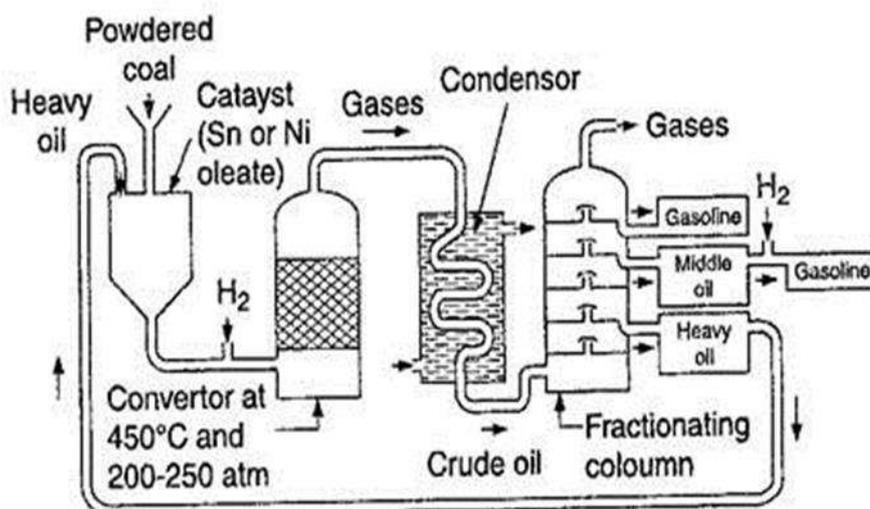
Coal is hydrogen deficient compound. If coal is heated with hydrogen at high temperature and high pressure, it is converted into gasoline. **This process of preparation of liquid fuel from solid coal** is called hydrogenation of coal.

Two methods are available for hydrogenation of coal. They are

- i) Bergius process (direct method)
- ii) Fischer – Tropsch Method (indirect method)

Bergius process

- In this process, the **finely powdered low ash coal, heavy oil, and catalyst powder (tin oleate or nickel oleate)** is mixed to form a **paste**.
- The paste is heated with hydrogen at a temperature of **400 - 450°C** and a pressure of **200 – 250 atmospheres** for about **1.5 hours** in a convertor.



- During this process, hydrogen combines with coal to form **saturated higher hydrocarbons** which further decomposes to yield **low – boiling liquid hydrocarbons (crude oil) while passing through a condenser.**
- Crude oil obtained is subjected to fractional distillation to yield i) Gasoline ii) Middle oil iii) Heavy oil.
- The yield of gasoline is about 60% of coal used.
- The middle oil is further hydrogenated yield more gasoline.
- The heavy oil is recycled for making paste with fresh coal dust.

Knocking

- In an internal combustion engine, a mixture of gasoline vapour and air at 1:17 ratio is used as a fuel.
- Due the presence of some impurities in gasoline the rate of oxidation becomes high that the final portion of the fuel – air mixture ignites instantaneously, producing an explosive sound. This is known as knocking.

Reason for knocking:

- Knocking follows a free radical mechanism, leading to chain growth that result in explosion.
- If the chain growth is terminated knocking will be stopped.
- Knocking property reduces the efficiency of the engine. The knocking property of petrol is expressed by octane number.

Ways to reduce knocking:

1. Adding Tetra – Ethyl Lead (TEL) as anti- knocking agent.
2. Adding aromatic phosphates as anti- knocking agent.

Octane number:

- It expresses the knocking characteristics of petrol.
- Octane number is defined as **the percentage of iso-octane present in a mixture of iso- octane and n-heptane.**
 - Iso-octane has antiknock value – 100(less knocking).
 - n-heptane has antiknock value – 0 (more knocking)
- The octane number of fuel can be improved by,
 - i) Blending petrol of high octane number with petrol of low octane number.
 - ii) The addition of antiknock agents like tetra ethyl lead(TEL)

Diesel oil

- It is a fraction obtained between 250 to 320⁰C during the fractional distillation of petroleum.
- It is a mixture of C₁₅H₃₂ – C₁₈H₃₈ hydrocarbons.
- Its calorific value is about 11000 kcal/ kg.
- It is used as a very good diesel engine fuel.

Cetane number

- The knocking property of diesel is expressed by cetane number.

- Cetane number is defined as the percentage of cetane present in a mixture of cetane and 2 – methyl naphthalene.

Cetane has cetane number = 100. So less knocking.

2 – Methyl naphthalene has cetane number=0. so high knocking.

- The cetane number of diesel oil can be increased by, adding additives called pre-ignition dopes. (e.g.) Ethyl nitrite, Iso – amyl nitrite etc.

Gaseous fuels

1. Natural Gas:

- Natural gas is obtained from wells dug in the oil bearing regions.
- When natural gas occurs along with petroleum in oil wells, it is called wet gas.
- When the gas is associated with crude oil it is called dry gas.
- Natural gas is purified to remove the impurities like water, dust, grit, H₂S, CO₂, N₂ and heavier liquefiable hydrocarbons.

Composition of Natural gas:

CH₄ - 70 -90%

C₂H₆ - 5-10

H₂ - 3%

CO + CO₂ – rest

Calorific value ranges from 12,000 – 14,000 kcal / m³

Uses: It is used as

- A domestic fuel.
- Manufacture of number of chemicals.
- A raw material for the manufacture of carbon black & H₂

2. Compressed natural gas (CNG) or Marsh gas

- CNG is a natural gas compressed to high pressure of 1000 atmosphere.
- It is used as a fuel.
- It is a less pollution causing fuel.
- During combustion, no sulphur and nitrogen gases are evolved. It is a better fuel than petrol and diesel for automobiles.

Composition

Methane – 88.5%

Ethane – 5.5%

Propane – 3.7%

Butane – 1.8%

Pentane – 0.5%

Properties

- i) It is a safer fuel.
- ii) Its ignition temperature is 550⁰C (higher temperature than gasoline and diesel).
- iii) CNG mixes with air easily.
- iv) CNG leads to lesser emission than gasoline.
- v) CNG vehicles do not have pollutants like smoke, SO₂, SO₃ etc.

Uses

- i) It is an excellent domestic fuel that can be transported through pipes.
- ii) It is used as a fuel in thermal power plants for generating electricity.

- iii) It is used as a source of hydrogen gas in fertilizer industries.
- iv) It is used as an alternative to petrol and diesel for transport of vehicles.

3. Liquefied petroleum gas (LPG)

- It is obtained as one of the top fractions in the fractional distillation of petroleum.
- It can be easily liquefied under pressure & stored in cylinders.
- It is a mixture of propane and butane.
- The composition is,
 - n-Butane** – 38.5%,
 - Iso – Butane** – 37 %,
 - Propane** – 24.5%, **Butylene** and ethane - rest
- Its **calorific value** is **27,800 Kcal /m³**.

Uses:

- It is used as cooking gas in domestic ovens as well as in furnaces.
- It is used as a motor fuel.

Advantages of LPG over other gaseous fuels:

1. It burns cleanly without leaving any residue.
2. It has higher calorific value than coal gas & natural gas.
3. It has high thermal efficiency.
4. It needs little care for maintenance.
5. It is free from CO & so less hazardous.

POWER ALCOHOL

When ethyl alcohol is used as fuel in internal combustion engine, it is called as "power alcohol". Generally ethyl alcohol is used as its 5-25% mixture with petrol.

Manufacture of Power Alcohol:

1. Manufacture of Ethyl Alcohol

Ethyl alcohol can be synthesized by fermentation of carbohydrates. This fermentation leaves only about 20% alcohol.



The concentration of alcohol can be increased up to 97.6% by fractional distillation which is called rectified spirit.

4. Manufacture of power alcohol from ethyl alcohol

- For the conversion of 97.6% of ethyl alcohol to absolute alcohol (100%) last traces of water must be removed.
- This can be done by distilling 97.6% of ethyl alcohol with benzene.
- It also can be done by distilling 97.6% of ethyl alcohol in the presence of dehydrating agent which holds water.
- Finally absolute alcohol is mixed with petrol at a concentration of 5 – 25% to get power alcohol.

Properties:

- i) Power alcohol has a lower calorific value (7000 cal / g).
- ii) It has high octane number (90).
- iii) Its anti-knocking properties are good.
- iv) It generates 10% more power than the gasoline of small quantity.

- v) Its compression ratio is also higher.

Use: It is used as a very good fuel in motors.

Advantages:

- Power alcohol is cheaper than petrol.
- Alcohol has property of absorbing any traces of water if present in petrol.
- Ethyl alcohol contains 'O' atoms, which helps for complete combustion of power alcohol and the polluting emissions of CO, hydrocarbon, particulates are reduced largely.

Disadvantages:

- Power alcohol has calorific value 7000cal/gm much lower than calorific value of petrol 11500cal/gm. So use of power alcohol reduces power output upto 35%.
- Ethyl alcohol may undergo oxidation reaction to form acetic acid, which corrodes engine parts.
- As it contains 'O' atoms, the amount of air required for complete combustion of power alcohol is lesser and therefore carburetor and engine need to be modified.
- Due to high surface tension, it causes starting trouble in motors.

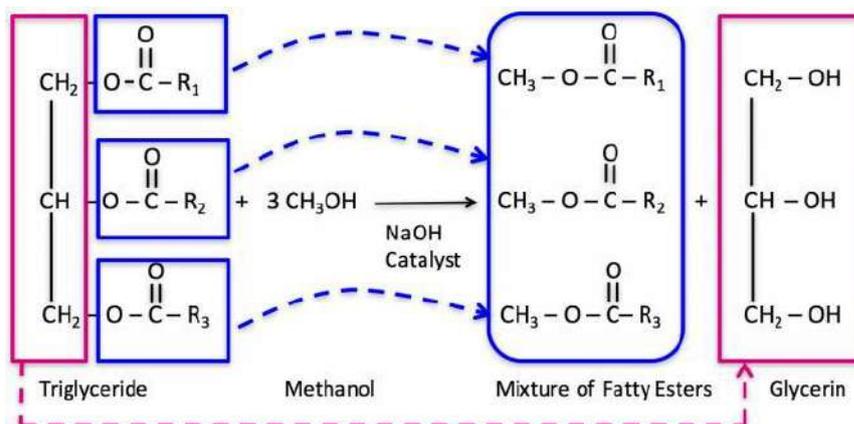
BIODIESEL

Definition & Explanation:

- Biodiesel is a renewable, clean-burning diesel.
- Biodiesel is defined as mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats which conform to ASTM D6751 specifications for use in diesel engines.
- Biodiesel is typically made by chemically reacting lipids (e.g., vegetable oil, animal fat with an alcohol producing fatty acid esters.
- Biodiesel can be used alone, or blended with petro diesel in any proportions. Biodiesel can also be used as a low carbon alternative to heating oil.

Making of biodiesel:

Biodiesel is made through a chemical process called **trans - esterification** whereby the glycerin is separated from the fat or vegetable oil. The process leaves behind two products -- methyl esters (biodiesel) and glycerin (a valuable byproduct usually sold to be used in soaps and other products).



Advantages:

- Biodiesel environment friendly because it is made from renewable resources.
- It has lower emissions compared to petroleum diesel.
- It is less toxic than table salt and biodegrades as fast as sugar.
- It is produced domestically from natural resources. So it is bio degradable.
- Its use decreases our dependence on imported fuel and contributes to our own economy.

Disadvantages:

- It gels during cold weather.
- It absorbs water from atmosphere.
- It decreases the efficiency of the engine.
- It emits about 10% higher nitrogen oxides than conventional petroleum.

Combustion

Combustion is an exothermic oxidation reaction in which a fuel burns in the presence of oxygen with the evolution of heat and light.

Calorific value

The total quantity of heat of liberated when unit mass of fuel is burnt completely.

Units for calorific value

- i) Calorie / gram.
- ii) Kilocalorie / kg.
- iii) British thermal unit(for solid or liquid fuels)

1. Higher calorific value (HCV) or Gross calorific value (GCV)

The total amount of heat produced when unit mass of the fuel is burnt completely and the products of combustion are cooled to room temperature.

Dulong's formula for the theoretical calculation of calorific value is,

$$\text{GCV or HCV} = [8080 C + 34500 (H - \frac{O}{8}) + 2240 S] \text{ kcal / kg}$$

where C, H, O & S represents the % of the corresponding elements.

2. Lower calorific value (LCV) or Net calorific value (NCV)

The net heat produced when unit mass of the fuel is burnt completely and the products of combustion are allowed to escape.

$$\text{NCV} = \text{GCV} - 0.09\text{H} \times 587 \text{ kcal / kg. (H = \% of H}_2 \text{ in the fuel)}$$

Problems based on calorific value

1. Calculate the gross and net calorific values of coal having the following compositions, carbon = 85%, hydrogen = 8%, sulphur = 1%, nitrogen = 2%, ash = 4%, latent heat of steam = 587 cal/g.

i) Gross calorific value

$$\begin{aligned}\text{GCV or HCV} &= [8080 \text{ C} + 34500 (\text{H} -) + 2240 \text{ S}] \text{ kcal /kg} \\ &= [8080 \times 85 + 34500 (8 -) + 2240 \times 1] \text{ kcal /kg} \\ &= [686800 + 276000 + 2240] \text{ kcal /kg} \\ \text{GCV or HCV} &= 9650.4 \text{ kcal / kg.}\end{aligned}$$

ii) Net calorific value

$$\begin{aligned}\text{NCV} &= \text{GCV} - \text{H} \times 587 \\ &= 9650.4 - 8 \times 587 \\ &= 9650.4 - 4716 \\ \text{NCV} &= 4934.4 \text{ kcal / kg}\end{aligned}$$

Ignition Temperature:

It is defined as, “the lowest temperature to which the fuel must be heated, so that it starts to burn smoothly”.

- For liquid fuels it is called as Flash point that ranges from 200 – 450⁰C.
- Ignition temperature for coal is 300⁰C.
- Ignition temperature for gaseous fuels is 400⁰C - 600⁰C.
- If Ignition temperature of the fuel is low it catches fire quickly.
- If Ignition temperature of the fuel is high it is difficult to ignite the fuel.

Spontaneous Ignition Temperature (SIT):

- It is defined as, “the minimum temperature at which the fuel catches fire spontaneously without external heating”.
- When the system reaches Spontaneous Ignition Temperature, the system burns on its own.

Explosive Range:

The minimum or maximum concentration levels of vapour of a flammable or combustible material at which an explosion will occur in a confined area if an ignition source is present. No explosion can occur in the presence of very low or very high concentrations.

Upper explosive Limit (UEL)

The maximum concentration of a gas or vapour that will burn in air is defined as the Upper explosive limit. Above this level, the mixture is too ‘rich’ to burn.

Lower explosive limit (LEL)

The minimum concentration of a gas or vapour that will burn in air is defined as the Upper explosive limit. Below this level the mixture is too lean to burn.

The range between the UEL and LEL is known as **explosive range or flammable range**.

Flue gas analysis (orsat method)

The mixture of gases (like CO₂, O₂ & CO) coming out from the combustion chamber is called flue gas.

- The analysis of a flue gas would give an idea about **the complete or incomplete combustion process**.
- The analysis of flue gas is carried out by using **Orsat's apparatus**.

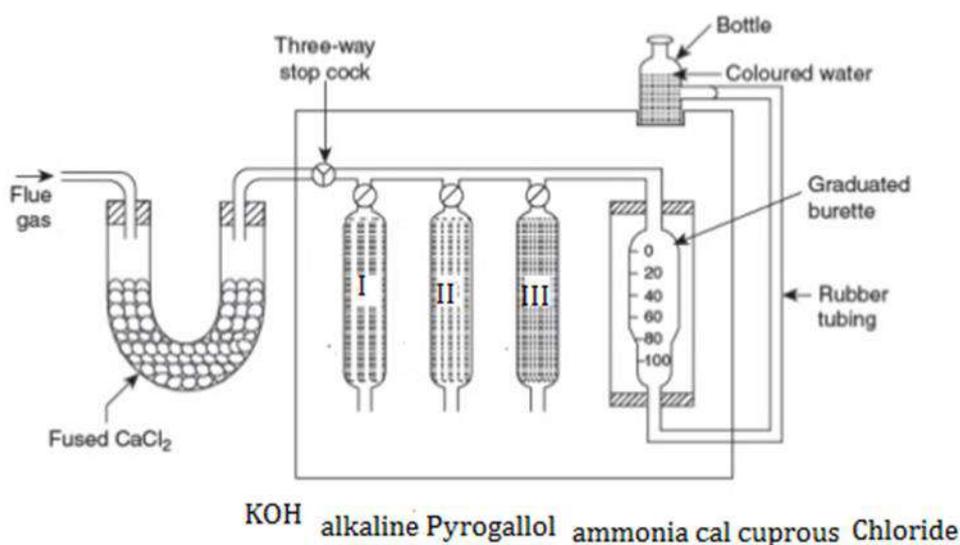
Description of Orsat's apparatus

- It consists of a horizontal tube.
- At one end of this tube, 'U' tube containing fused CaCl₂ is connected through 3 – way stop cock.
- The other end of the tube is connected with a graduated burette.
- The burette is surrounded by a water jacket to keep the temperature of the gas constant.
- The lower end of the burette is connected to a water reservoir by means of a rubber tube.
- The level of water in the burette can be raised or lowered by raising or lowering the reservoir.
- The horizontal tube is also connected with three different absorption bulbs 1, 2 and 3 for absorbing CO₂, O₂ and CO.

Bulb 1 contains **KOH** and it absorbs **CO₂** only.

Bulb 2 contains **alkaline pyrogallol** and it absorbs **CO₂** and **O₂**.

Bulb 3 contains **ammoniacal cuprous chloride** and it absorbs **CO₂, O₂ and CO**.



Working

- The three way stop cock is opened to the atmosphere and the burette is completely filled with water and air is sent out.
- The burette is filled with flue gas to 100 cc by raising or lowering the reservoir. Now the 3- way stop cock is closed.

1. Absorption of CO₂

- The bulb 1 is opened and all the gas is passed into bulb1 by raising the level of water in the burette.
- The gas enters into bulb1 where CO₂ is absorbed by KOH. The gas is again sent to the burette.
- The process is repeated several times to ensure complete absorption of CO₂.
- The decrease in volume of the flue gas = the volume of CO₂ in 100cc of the flue gas.

2. Absorption of O₂

- Bulb 1 is closed and bulb 2 is opened.
- The gas is again sent into bulb 2 where O₂ in the flue gas is absorbed by alkaline pyrogallol.
- The decrease in volume of the flue gas = the volume of O₂.

3. Absorption of CO

- Bulb 2 is closed and bulb 3 is opened.
- The remaining gas is sent into bulb 3, where CO is absorbed by ammoniacal cuprous chloride.
- The decrease in volume of flue gas = the volume of CO.
- The remaining gas in the burette after the absorption of CO₂, O₂ and CO is taken as nitrogen.

Significance

- i) It gives an idea about the complete or incomplete combustion.
- ii) If the flue gas contains considerable amount of CO, it indicates incomplete combustion and short supply of O₂.
- iii) If the flue gas contain considerable amount of O₂, it indicates complete combustion and excess supply of O₂.

Question Bank Part A

1. Write the characteristics of a good fuel.

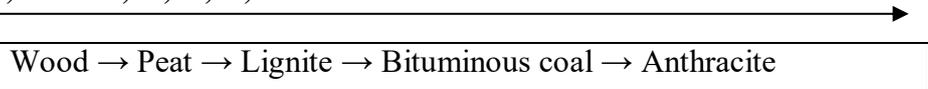
A good fuel should have High calorific value, Moderate ignition temperature, Low moisture content, Low non-combustible matter, Low cost.

2. What is coalification or metamorphism of coal?

The process of alteration of vegetable matter into coal is called coalification.

3. What are the different varieties of coal?

Moisture, volatile, H, O, N, S contents decreases





4. What is fixed carbon?

It is the pure non-volatile, carbon content present in the coal. Higher the percentage of fixed carbon greater is its calorific value.

5. What is carbonization of coal?

The process of strong heating of coal in the absence of air & converting it into coke is known as carbonization of coal.

6. What is metallurgical coke?

When Bituminous coal is heated strongly in the absence of air, the volatile matter escapes out and a hard, strong, porous and coherent mass called metallurgical coke is obtained.

7. How is coke different from coal?

In coke % of fixed carbon is high, % of moisture, volatile matter & ash content are low in coke than coal.

8. What is the difference between caking coals & coking coals?

When coal is heated strongly in the absence of air, the mass becomes soft, plastic & fuses to give a coherent mass called caking coals. But if the mass produced is hard, porous & strong it is called coking coals.

9. What is the drawback of presence of sulphur in coal?

Presence of sulphur in coal is undesirable because SO_2 and SO_3 are harmful and corrode the equipments.

10. What is meant by refining of petroleum?

The process of removing impurities and separating crude oil into various fractions is called as Refining of petroleum.

11. What is Cottrell's process in crude oil refining?

The crude oil is an emulsion of oil and salt water. The crude oil is allowed to flow between two highly charged electrodes. Here the water droplets combine to form large drops which separate out from oil.

12. How to improve the anti knocking properties of gasoline or octane number?

The octane number of fuel can be improved by,

- i) Blending petrol of high octane number with petrol of low octane number.
- ii) The addition of antiknock agents like tetra ethyl lead (TEL).

13. What is knocking in petrol engine?

Due the presence of some impurities in gasoline the rate of oxidation becomes high that the final portion of the fuel – air mixture ignites instantaneously, producing an explosive sound. This is known as knocking.

14. Define octane number. How can it be improved?

Octane number is defined as the percentage of iso-octane present in a mixture of iso- octane and n-heptane. The octane number of fuel can be improved by the addition of antiknock agents like tetra ethyl lead (TEL).

15. Why should leaded petrol not be used?

Lead deposits on the spark plug & on cylinder walls, which is harmful to engine life. It also produces air pollution.

16. Define cetane number. How can it be improved?

Cetane number is defined as the percentage of cetane present in a mixture of cetane and 2 – methyl naphthalene. The cetane number of diesel oil can be increased by, adding additives called pre-ignition dopes. (eg) Ethyl nitrite, Iso – amyl nitrite etc.

17. What is meant by hydrogenation of coal?

If coal is heated with hydrogen at high temperature and high pressure, it is converted into gasoline. This process of preparation of liquid fuel from solid coal is called hydrogenation of coal.

18. Water gas is superior to producer gas. How?

- Its calorific value is higher (2800 kcal /m³). It possesses less amount of nitrogen content.
- It is used for the production of H₂, power alcohol & carbureted water gas.

19. Arrange LPG, water gas, bio gas & producer gas in increasing order of their calorific values.

Producer gas (1300 kcal/m³) < water gas (2800 kcal/m³) < bio gas < LPG (27,800 Kcal /m³).

20. What is meant by combustion of fuels?

Combustion is an exothermic oxidation reaction in which a fuel burns in the presence of oxygen with the evolution of heat and light.

21. Mention the combustible & non combustible constituents present in the fuel.

Combustible constituents: C, H, S, & O

Non combustible constituents: N, CO₂

22. Define calorific value of a fuel.

The total quantity of heat of liberated when unit mass of fuel is burnt completely.

23. Define GCV & LCV of a fuel.

GCV is the total amount of heat produced when unit mass of the fuel is burnt completely and the products of combustion are cooled to room temperature. LCV is the net heat produced when unit mass of the fuel is burnt completely and the products of combustion are allowed to escape.

24. Give the Dulong's formula for the calculation of GCV & LCV of a fuel.

$$\text{GCV or HCV} = \frac{1}{100} [8080 C + 34500 (H - \frac{O}{8}) + 2240 S] \text{ kcal / kg}$$

Where C, H, O & S represents the % of the corresponding elements.

$$\text{NCV} = \text{GCV} - 0.09H \times 587 \text{ kcal / kg. (H = \% of H}_2 \text{ in the fuel)}$$

Part B

1. Compare solid fuels, liquid fuels & gaseous fuels. (8)

2. Explain the proximate analysis of coal.(8)
 3. Explain the ultimate analysis of coal.(8)
 4. What is metallurgical coke? Give its characteristics.(6)
 5. How is metallurgical coke manufactured by Otto Hoffman's method?(8)
 6. What is petroleum? Explain the refining of petroleum with fractional distillation.(8)
 7. How is gasoline synthesized by Bergius process?(8)
 8. Write a short note on a) knocking b) octane number.(8)
 9. Write a short note on a) Diesel oil b) cetane number.(6)
 10. Write a short note on a) Natural gas b) Compressed Natural Gas (CNG) c) LPG.(8)
 11. Explain the manufacture of Producer gas & give its uses.(8)
 12. Explain the manufacture of water gas & give its uses.(8)
 13. Write a short note on a) Power alcohol b) Bio diesel.(8)
 14. Explain the analysis of flue gas by Orsat's method.(8)
- Write a short note on Ignition Temperature &Explosive range.(4)