MODULE – IV

FUELS AND COMBUSTION

4.1 Fuels: Introduction

Fuels are the major source of energy for all industrial and domestic activities. Fuels may exist in solid, liquid and gaseous state. The choice of fuels depends on their avilability, handling, storage, pollution, etc. Fuels undergo combustion to release energy, which is due to the rearrangement of the valence electrons in the atoms of the fuel.

4.1.1 Definition of fuel

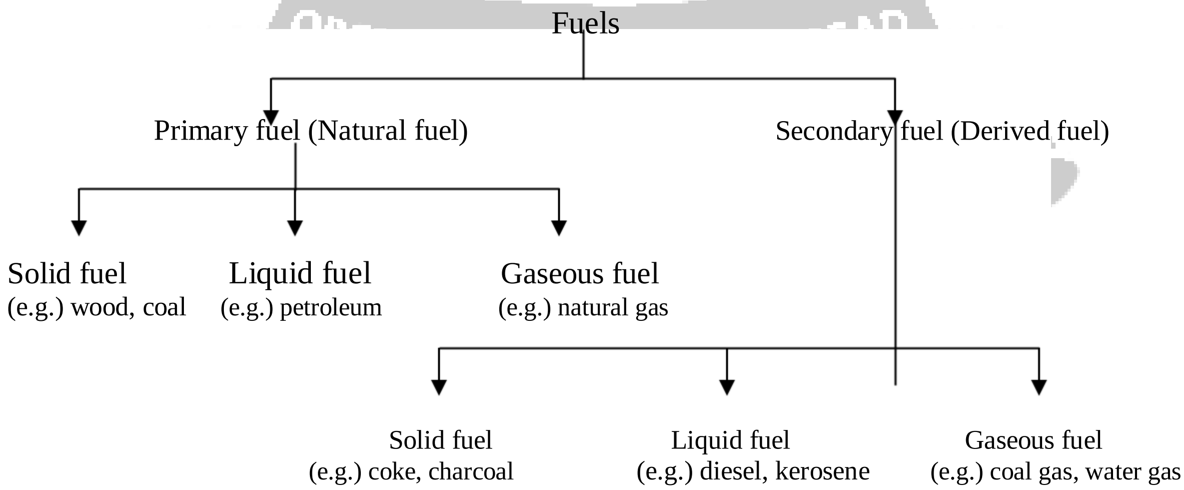
Fuel is a combustible substance containing carbon as major constituent, which gives out heat energy on burning. Examples: coal, petroleum, natural gas.

$$\text{Fuel} + O_2 \longrightarrow CO_2\uparrow + H_2O\uparrow \text{ (combustion products)} + \text{heat}$$

4.1.2 Characteristics of a good fuel

1. A good fuel should have,
   - ➢ High calorific value.
   - ➢ Moderate ignition temperature and velocity of combustion.
   - ➢ Low moisture content, non-combustible matter.
2. It should be,
   - ➢ Cheap and readily available.
   - ➢ Easy to transport.
3. The products of combustion must be harmless.
4. Combustion must be easily controllable.
5. Must not burn with much smoke.

4.1.3 Classification of fuels



4.1.4 Coal (Solid fuel)

- Coal is a fossil fuel which mainly contains carbon and is formed as a result of alteration of vegetable matter under favourable conditions (high temperature and pressure) under the earth.
- It consists of C, H, N, O & non-combustible inorganic matter.

Coalification or Metamorphism

The process of conversion of vegetable matter (wood) into coal is called Coalification. The flowchart showing the sequential conversion of wood into coal is given as,

Wood → Peat → Lignite → Bituminous coal → Anthracite

4.1.5 Classification of coal (Varieties of coal)

Fuel	Property	% of carbon	C.V(k.cal/kg)	Applications
Wood	-	50	4000-4500	Domestic fuel
Peat	Brown fibrous jelly like mass	50-60	4125- 5400	Soil amendement
Lignite	Soft, brown coloured coal	60-70	6500-7100	Steam generation
Bituminous	Dark grey coloured coal	80-90	8000-8500	Making coal gas & metallurgical coal
Anthracite	Black of dark brown coloured high rank coal	90-98	8650-8700	Smithing coal, Coking coal, Power generation

4.1.6 Analysis of coal

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

1. Proximate analysis
2. Ultimate analysis

1. Proximate analysis

Proximate analysis is a qualitative analysis which involves the determination of percentage of moisture content, volatile matter, ash content and fixed carbon in coal. Based on the results obtained the coal can be ranked as best or least variety.

(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 isfound out and the percentage of moisture is calculated as,

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

2. Ultimate analysis

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

1. Determination of 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.

$$C + O_2 \longrightarrow CO_2\uparrow$$

$$H_2 + \frac{1}{2} O_2 \longrightarrow H_2O\uparrow$$

- The liberated CO_2 and H_2O vapours are absorbed by KOH and anhydrous $CaCl_2$ tubes of known weights.

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

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

- 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,

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

$$\text{\% of hydrogen in coal} = \frac{\text{Increase in weight of } CaCl_2 \text{ tube}}{\text{Weight of coal sample}} \times \frac{2}{18} \times 100$$

2. Determination of nitrogen

Nitrogen content is determined by kjeldahl's method.

- A known amount of powdered coal sample is heated with conc. H_2SO_4 in a long necked flask.
- Nitrogen in the coal is converted into Ammonium sulphate (clear solution).

$$2N + 3H_2 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$$

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

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

$$NH_3 + HCl \longrightarrow NH_4Cl$$

- 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,

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

3. Determination of 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 $BaCl_2$ solution so that the sulphates are precipitated as $BaSO_4$.
- The precipitate is filtered, dried and weighed.
- From the weight of $BaSO_4$, sulphur present in the coal is calculated as,

$$\textbf{\% of sulphur in coal} = \frac{\text{Weight of } BaSO_4}{\text{Weight of coal sample}} x \frac{32}{233} x 100$$

4. 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.

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

5. Oxygen

The percentage of oxygen is calculated as,

% of oxygen in coal = 100 - % of (C + H + N + S + ash)

Significance of ultimate analysis

1. Higher the percentage of carbon and hydrogen, better is the quality of coal 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.

4.2.Carbonization

Carbonization is the process in which coal is strongly heated in the absence of air and is converted into coke.

4.2.1 Types of carbonization

a) Low-temperature carbonization - heating coal at 500 – 700^{0}C.

b) High-temperature carbonization - heating coal at 900 – 1200^{0}C.

4.2.2 Differences between low-temperature & 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.

4.2.3 Coke

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

4.2.4 Metallurgical coke

When bituminous coal is heated strongly in the absence of air, it loses volatile matter and becomes lustrous, dense, porous and coherent mass called metallurgical coke. This process of conversion of coal into coke is called **carbonization.**

4.2.5 Manufacture of metallurgical coke by Otto - Hoffman's method- Importance of Otto - Hoffman's method

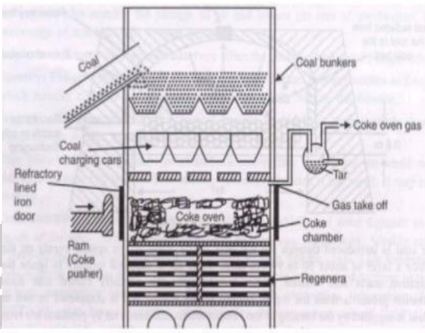
Otto – Hoffman's modern by-product method is considered the best method because,

- Heating is done on the basis of **'regenerative system of heat economy'** by using heat energy of the waste flue gases.
- It is possible to recover the various by –products.

Description of the oven

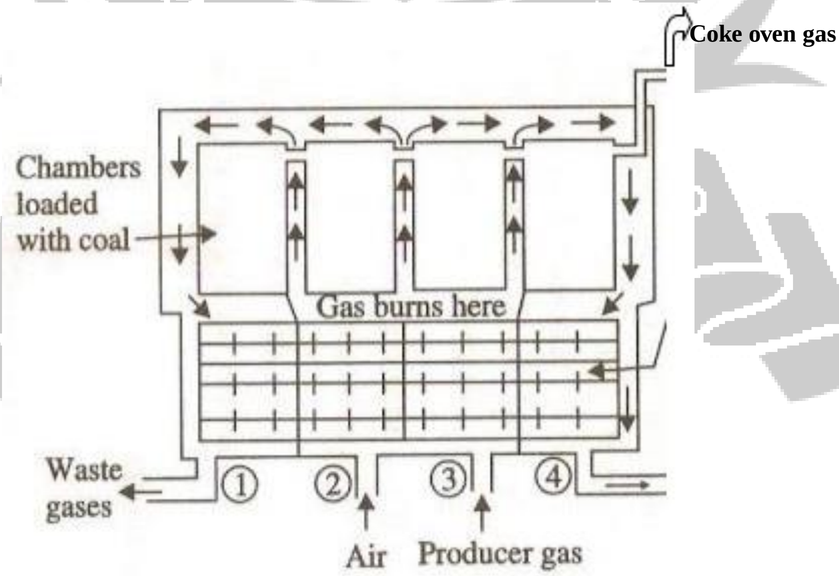
- The oven consists of number of silica chambers.
- The chambers are about 10 – 12 m long, 3 – 4 m height and 0.42 – 0.45 m wide.

- Each chamber has a charging hole (top), gas off- take valve and iron door (end) for discharging coke.
- The air required for the combustion of coal is preheated in regenerators.



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 **2ndand 3rd** hot regenerators.
- **Hot flue gases** produced during carbonization come out through **1st and 4th**regenerators raising the temperature to 1000^{0}C.
- The fuel gas is now passed through the **1stand 4th** regenerators (preheating).
- Flue gases come out through the **2ndand 3rd** regenerators raise the temperature to 1000^{0}C. This cycle goes on.
- This process is known as '**regenerative system of heat economy'.**

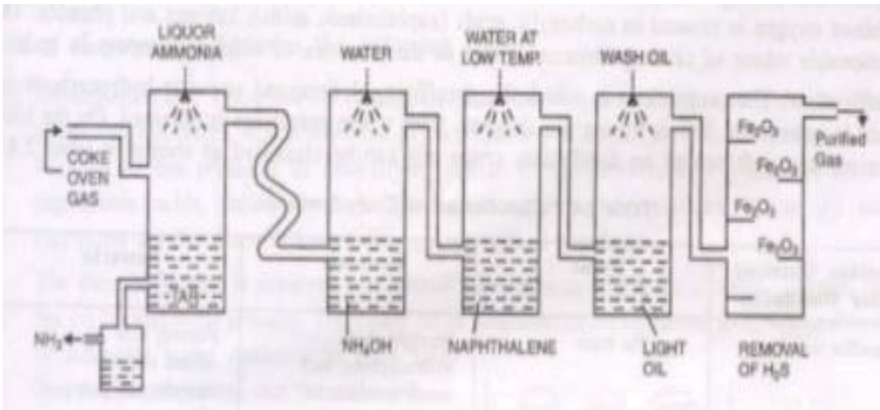


- The **time taken** for the carbonization process is **11 to 18 hours.**

- When the process is over, coke is removed from oven and **cooled by dryquenching.**

Recovery of by – Products:

The gas coming out from the oven is known as ‘coke oven gas’ consisting of tar, ammonia, Naphthalene, benzene, H_2S, etc. The method of recovery of these by-products is given below,



By- products	Recovery procedure
Tar	-spraying liq.NH_3. -NH_3 is got back by heating process.
Ammonia	-spraying water. -Ammonia is converted to NH_4OH.
Naphthalene	-spraying cool water. - naphthalene condenses.
Benzene	-spraying petroleum. - benzene condenses to liquid.
H_2S	-passing remaining gas through purifier packed with moist Fe_2O_3. -H_2S is retained.
Purified coal gas	-Final product that can be used as a gaseous fuel.

Advantages

- Time taken (11-18 hours) for carbonization is less compared to other methods.
- Improved thermal efficiency.
- Valuable by-products are obtained.
- It is a regenerative system.
- The yield of coke is 70%.