UNIT-4
Fuels and Combustion

Basic terms and definition

Fuel	A fuel is a combustable substance which on proper burning in presence of oxygen or air gives large amount of heat energy that can be used econamically for domestic and industrial purpose.
Combustion	Combustion process is an exothermic chemical reaction which is accompanied by heat and light.
Calorific value	The total amount of heat liberated when a unit mass of the fuel is burnt completly in presence of sufficent quantity of air / oxygen.
Gross calorific value	The total amount of heat liberated when a unit mass of the fuel is completly burnt and the products of combustion are cooled down to room temperature is called gross calorific value.
Net calorific value	The amount of heat liberated when a unit of fuel is completly burnt and the combustion products are allowed to ecape is called net calorific value.
Coalification os coal	The process of convesion of vegetable matter to anthracite is called coalification or metamorphism of coal.
Cabonisation of coal	The process of preparing coke from bituminous coal is known as carbonisation of coal.
Proximate analysis	It is an imperial analysis, used for the determination of the moisture, volatile matter, ash and fixed carbon in coal.
Ultimate analysis	It is the elemental analysis of coal used for the determination of carbon, hydrogen, sulphur, nirogrn, ash and oxygen.
Refining of Petroleum	The process of removal of impurities from crude oil and separation of various fractions with different boiling ranges is called refining of petroleum.
Knocking	Knocking is a kind of explosion due to rapid pressure rise occuring in an IC engine. Thw knocking tendency decreses in the following order. Straight chain paraffins > Branched chain paraffins > Cycloparaffins > Olefins > Aromatics.
Octane number	The percentage of iso octane present in a mixture of iso octane and n-heptane which has the same knocking characteristics as the gasoline (Petrol) sample under test.
Cetane number	The percentage of hexa decane present in a mixture of hexa decane and 2- methyl naphthalene, which has the same knocking characteristics as the diesel sample under test.
Synthtic petrol	Petrol synthesised either by polymerizations of low molecular mass olifins and alkanes or from finely powdered coal and heavy oil is called synthetic petrol.

Power alcohol	When ethyl alcohol is used as an additive to motor fuels to act as a fuel for internal combustion engines, it is called power alcohol.
Flue gas	The mixture of gases like CO_2, O_2, CO etc coming out from the combustion chamber is called flue gas.
Water gas	Water gas is a mixture of CO and H_2 with small amount of N_2.
Producer gas	Producer gas is a mixture of CO and N_2 with small amount of H_2.
Coal gas	Coal gas is a mixture of methane and hydrogen. It is obtained by Cabonisation of coal.
Bio gas	Bio gas is a type of natural gas obtained by the degradation of biological matter by the bactirial action in the absence of free oxygen.
Gobar gas	Gobar gas is an important bio gas obtained by the anaerobic formentation of cattle dung.

Concepts:

Introduction: **-** A chemical fuel is any substance used to produce heat and power by combustion. Fuels are primarily used for heating but they have very important functions. Fuels not only supplies heat but also acts as reducing agents.

Fuels: - The fuel resources of the world have been estimated differently by different authorities. To give a general idea, it may they said that the world's gas supplies are likely to last fifteen years, oil eighty years, coal five hundred years and nuclear fission materials two thousand years. India has sufficiently large deposits of coal but these are small when compared with some other developed countries. When people think of petroleum, their attention naturally goes to petrol. It may be mentioned here that petrol is about 1-8 of the total petroleum products. Diesel oil, furnace oil, lubricants etc and numerous other materials for the manufacture of which petroleum is the basic raw material also have their importance.

Classification of fuels: - Fuels are classified according to whether they occur in nature (primary fuels) are prepared (secondary fuels) and according they are in the solid, liquid or gaseous state.

State	Natural(Primary)	Prepared(Secondary)
Solid	Wood, peat, lignite, coal.	Charcoal, coke.
Liquid	Petroleum.	Petroleum by products.
Gaseous	Natural gas.	Coal gas, coke oven gas, producer gas, water gas, blast furnace gas.

Characteristics of a good fuel:- A good fuel should possess the following characteristics for its selection for a particular purpose.

- It should have less moisture and ash.
- It should possess high calorific value.
- The velocity of the combustion should be moderate.
- It should be cheap and readily available.
- It must be easy to handle, store and transport of minimum cost.
- Combustion of the fuel should be easily controlled.
- It should have higher carbon content.
- It should not produce undesirable products or toxic gases.

Solid Fuels:-

Advantages:-

- They are easy to transport.
- They are convenient to store without any risk.
- They possess moderate ignition temperature.
- Their cost of production is less.

Disadvantages:-

- They contain high ash content.
- Excess of air is required for complete combustion.
- Calorific value is less when compare with liquid & gaseous fuels.
- Combustion operations cannot be controlled easily.

Coal: - Coal is the primary solid fuel which is formed from the remains of decaying vegetable matter under the influence of heat, pressure and bacterial action underneath the earth. It is composed of C, H, O, N and S atoms besides some non- combustible inorganic matter.

Classification of coal:- Various forms of coal are recognized on the basics of rank or degree of alteration from the wood.

Wood → Peat → Lignite → Bituminous → Anthracite.

- Calorific value, hardness, carbon content ----------> Increases.
- Volatile matter, moister, H, O, S and N content ---------- > Decreases.

i) Peat: It is a brown fibrous jelly like mass and recognized as the first stage in coalification of wood. The average composition of air dried peat is C= 57%, H=6%, O=35% and ash= 2.5 – 6%.Its calorific value is about 5400 K.Cal/Kg.

ii) Lignite: It is a brown colored coal between the peat and bituminous coal. The average composition of air dried lignite is C= 60 – 70%, H=5%, O=20%. Lignite is easily ignited and burns with a long brown flame. Its calorific value is about 6500 – 7100K.Cal/Kg.

iii) Bituminous coal: It is the common variety of coal and carbon content range from 78 to 90% and volatile matter 20 to 45%. Its calorific value is about 8000-8500 K.Cal/Kg and used in manufacture of metallurgical coke, coal gas etc.

iv) Anthracite coal: It is the highest rank of coal and the carbon content of this coal is 92 -98%. Its calorific value is about 8650-8700 K.Cal/Kg. It has low volatile matter and moisture.

Manufacture Of METALLURGICAL COKE By Otto-Hoffmann's By Product Oven Process:- The process of preparing coke from coal is known as carbonization of coal. When bituminous coal is heated strongly in the absence of air, the dense strong, porous mass obtained is called metallurgical coke.

Characteristics of Metallurgical coke:-

i) Purity: - It should contain less percentage of moisture, ash, phosphorus and sulphur.

ii) Porosity: - It should be porous, so that combustion should be uniform and complete.

iii) Strength: - The mechanical strength of coke should be very high, to withstand the load of overlying solids like ore and flues.

iv)Size:- Coke should be have medium size, i.e,. neither too big nor too small in size.

v) Calorific value:- Coke should possess a very calorific value.

vi) Cost:- Coke should be cheap and easily available.

vii)Combustibility:- Coke should burn easily.

viii) Reactivity:- The reactivity of coke should not be very high.

Manufacture of Metallurgical Coke by "Otto-Hoffmann's By-Product Oven Process":- In order to increase the thermal efficiency of carbonization process and to recover the valuable by-products, otto-haffmann developed a modern by-product coke oven. It consists of number of narrow silica

chambers. Each chamber is provided with a charging hole at the top, a gas off-take and a refractory lined cast iron door at each end for discharging coke. Coal is introduced into the chamber and the chambers are closed. The ovens are heated to 1200°c by burning a gaseous fuel and usually employ a regenerative principle to active economical heating. The fuel gases produced during combustion are passed to the regenerators chequer brick work that takes up the heat and gets heated to about 1000°c. The flow of heating gases is the reversed so that the hot flue gases preheat the other chambers. The heating is continued till the evolution of volatile matter ceases completely which is about 11-18 hours. When coke is formed, a massive raw pushes the red hot coke outside. It is subsequently quenched by water spray. The coke obtained by dry quenching is drier, clean and stronger than wet quenched coke.

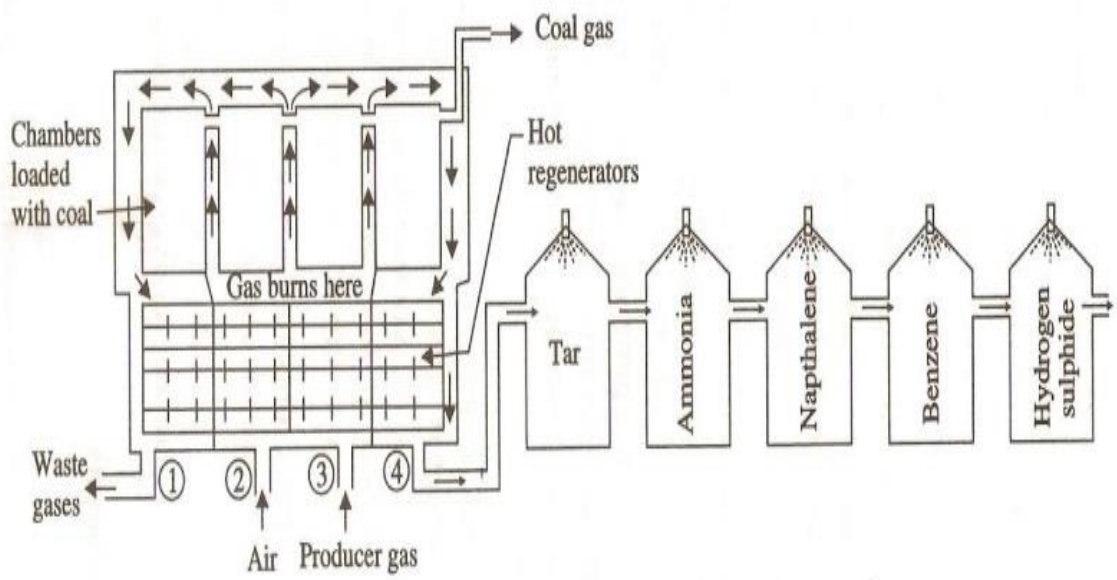


Fig. **Otto-Hoffmann's By-Product Oven Process**

Recovery of by-products:- The gas coming out from the oven is called coke oven gas and is composed of NH_3, H_2S, naphthalene, tar, benzene, etc,. This can be separated from each other.

Coal tar:- The coke oven gas is passed through a tower where liquor ammonia is sprayed from the top. Dust and tar gets collected in a tank which is heated by steam coils to recover ammonia back.

Ammonia:- The gas is then passed through a tower where water is sprayed. Ammonia goes in to solution forming NH_4OH.

$$NH_3 + H2O \text{ --------> } NH_4OH.$$

Naphthalene:- The gas is then passed to a cooling tower where water is sprayed at a very low temp. Condensation of some gases takes place and naphthalene is recovered.

Benzene:- The gas is than sprayed with petroleum. Hence benzene and its homologues are recovered.

Removal of hydrogen sulphide:- The gas is passed through a purifier filled with ferric oxide.

$$Fe_2O_3 + 3\ H_2S \text{ --------> } Fe_2S_3 + 3H_2O.$$

After all the Fe_2O_3 is exhausted the purifier is exposed to atmospheric air when Fe_2O_3 is regenerated and leaving So_2 gas.

$$Fe_2O_3 + 4\ O_2 \text{ ------> } 2Feo + 3\ So_2.\uparrow$$

$$4FeO + O_2 \text{ ---------> } 2\ Fe_2O_3.$$

Analysis of coal:-

i) Proximate analysis: It is an imperial analysis, used for the determination of the moisture, volatile matter, ash and fixed carbon in coal.

ii) Ultimate analysis: It is the elemental analysis of coal used for the determination of carbon, hydrogen, sulphur, nitrogen, ash and oxygen.

Liquid Fuels:-

ADVANTAGES:-

- Liquid fuels are clean and require less amount of air for complete combustion.
- They possess higher calorific value than solid fuels.
- They are easy to transport through pipes.
- They are used as internal combustion fuels.
- They burn without forming dust, ash, etc.

Disadvantages:-

- Care must be taken during storage.
- Cost is relatively higher than solid fuels.
- They give bad odour.
- Greater risk of fire hazards.

Petroleum Or Crude Oil:- The word petroleum is derived from the Latin 'Petra' (rock) and 'Oleum' (oil). It is also known as crude oil or mineral oil. Petroleum is the main source of liquid fuels. Petroleum is a dark greenish-brown viscous liquid found in the earth's crust. The average composition of petroleum shows;

C= 79.5 – 87.1/.

H= 11.5-14.8/.

S= 0.1-3.5/.

O+N= 0.1-0.5/.

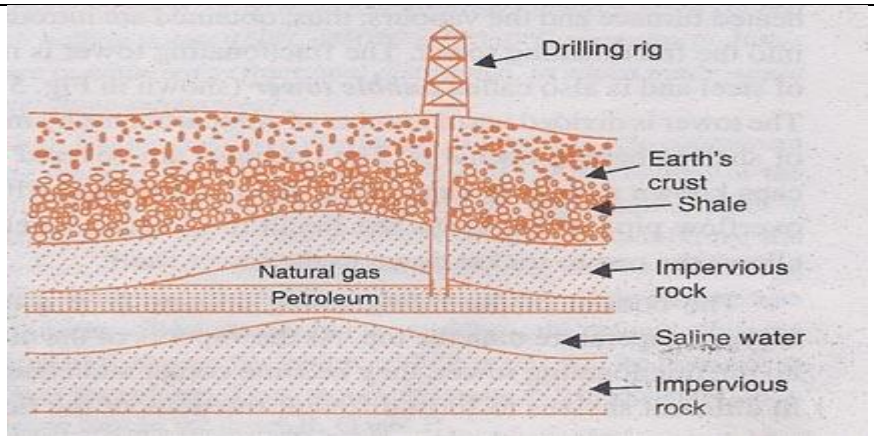
Classification Of Petroleum:- According to chemical nature, there are three types of petroleum;

a) Paraffin-base petroleum compound of saturated hydrocarbons up to $C_{35}H_{72}$ which are semi-solids, called waxes.

b) Asphaltic-base petroleum composed mainly of naphthalene's and cycloparaffins with smaller amount of paraffin's and aromatics.

c) Mixed-base petroleum contains both the above type of compounds but is rich in semi-solid waxes.

Mining of Petroleum:-Petroleum is brought to the surface by drilling holes up to oil bearing area and sinking pipes. Generally, oil is pushed out due to hydrostatic pressure of natural gas. When the pressure of natural gas is not sufficient, then air pressure is applied through lift pumps to force the oil out of the well. Two coaxial pipes are lowered to the oil reservoir; compressed air is forced through the outer pipe, whereby the oil comes out through the inner pipe which is sent to the refineries for further processing.



Refining of Petroleum:- Petroleum obtained from the ground is a mixture of oil and unwanted impurities (water, dirt, sulphur compounds, etc,.). The process of removal of impurities from crude oil and separation of various fractions with different boiling ranges is called oil refineries. The whole process of refining of petroleum involves the following steps.

Step-1: Separation of water (Cottrell's process):-

The crude oil is an emulsion of oil and salt water. It is allowed to flow through two highly charged electrodes. The colloidal water droplets coalesce to form large drops which separate out from the oil.

Step-2: Removal of sulphur compounds:-

Sulphur compounds have objectionable properties of pollution. When the crude oil is treated with copper oxide, a reaction occurs with sulphur compounds which results in the formation of copper sulphide ppt which is then removed by filtration.

Step-3: Fractional distillation:-

The crude oil is then subjected to about 400°c temp in an iron retort. All volatile constituents are evaporated. The constituents, tar and asphalt, do not vapourise and they settle at the bottom of the retort. The hot vapours are then passed through a fractionating column. It is a tall cylindrical tower containing a number of horizontal stainless steel trays at a short distance. Each tray is provided with a small chimney, covered with a loose cap. As the vapours go up, they begin to cool and fractional condensation takes place at different levels of column. Higher boiling fractions condense first while lower boiling fractions condense next. Thus the crude oil is fractioned in to different fractions depending upon their boiling ranges.

Important petroleum products and their uses:-

i) Gasoline or Petrol:- It is obtained b/w 40-120°c and is a mixture of hydrocarbons such as C_5H_{12} to C_9H_{20}. Approximate composition is C=84/. , H=15/. , N+S+O=1/. Its calorific value is 11250 K.cal/kg and is used as a fuel for internal combustion engines of automobiles and aircrafts.

ii) Kerosene oil:- It is obtained b/w 180-250°c and is a mixture of hydrocarbons such as $C_{10}H_{12}$ to C_{16}H34. Approximate composition is C=84/. , H=16/. , S=less than 0.1/. Its calorific value is 11,100K.cal/kg and used as fuel in stores, jet engine fuel and for making oil gas.

iii) Diesel oil: - It is a fraction obtained b/w 250-320°c and is a mixture of $C_{15}H_{32}$ to $C_{18}H_{38}$ hydrocarbons. Its calorific value is 11000K.cal/kg and is used as a diesel engine fuel.

FRACTION	BOLING RANGE	COMPOSITION	USES
Uncondensed gas	Below 30°c	C_1-C_4	As domestic or industrial fuel(LPG)
Petroleum ether	30-70°c	C_3-C_7	As a solvent
Gasoline or petrol	40-120°c	C_5-C_9	As a motor fuel, solvent and in dry cleaning
Naphtha	120-180°c	C_9-C_{10}	As a solvent and in dry cleaning.
Kerosene oil	180-250°c	C_{10}-C_{16}	As an illuminant, fuel for stoves
Diesel oil	250-320°c	C_{15}-C_{18}	As a fuel for diesel engines
Heavy oil	320-400°c	C_{17}-C_{30}	For setting gasoline by cracking process
This on refractionation gives			
a)Lubricating oil			As lubricant
b)Petroleum jelly			Used in cosmetics and medicines.
c)grease			As lubricant
d) Paraffin wax.			In candles, boot polishes wax paper.

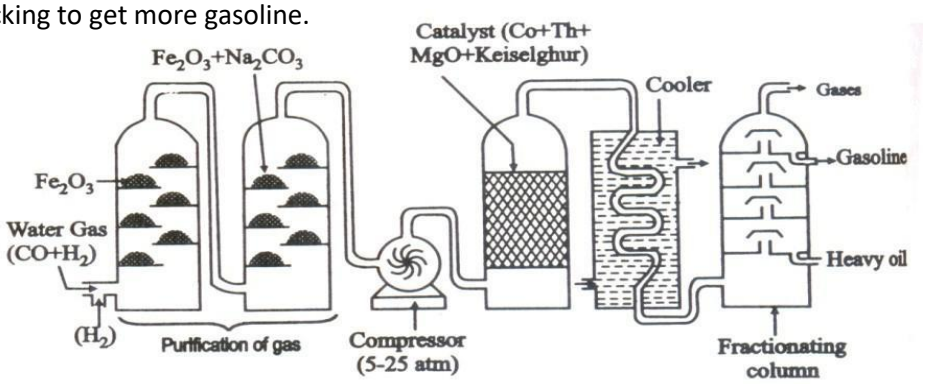
Synthetic Petrol:- Petrol is generally synthesized by the following two methods.

i) Fischer-Tropsch Process:- Water gas is a mixture of carbon monoxide and hydrogen ($CO+H_2$), produced by passing steam over red hot coke. It is mixed with hydrogen. The gaseous mixture (water gas + hydrogen) is purified by passing over Fe_2O_3, to remove H_2S, then passing over Fe_2O_3, Na_2Co_3 mixture to remove organic sulphur compounds. The purified gas is compressed to 5 to 25 atm at 200-300°c passed through a converter containing catalyst which is a mixture of 100 parts cobalt, 5 parts thorium, 8 parts magnesium and 200 parts kieselguhr. A mixture of saturated and unsaturated hydrocarbons is formed.

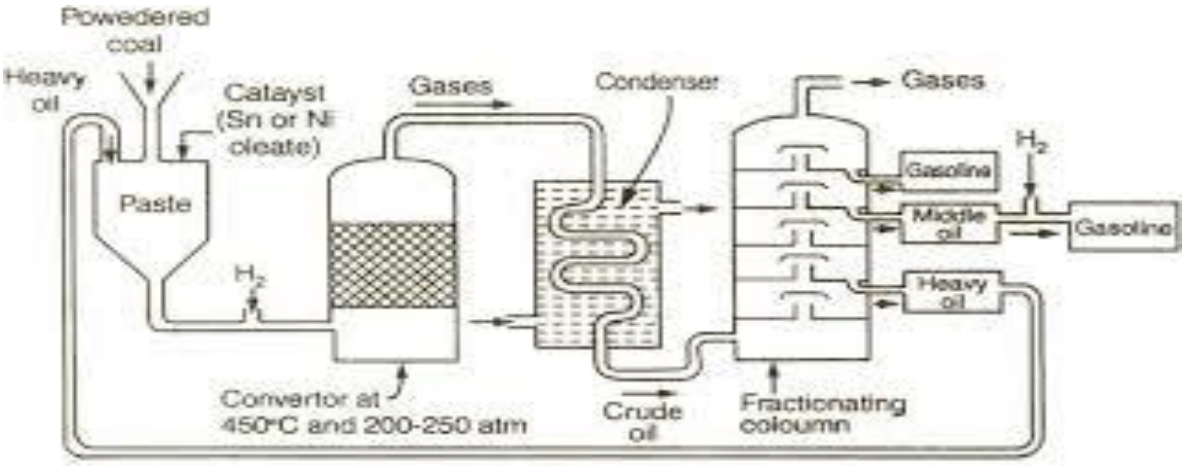
$$n\ Co + 2nH_2 \text{ -------> } C_nH_{2n} + nH_2O.$$

$$n\ Co + (2n+1)H_2 \text{ --------> } C_nH_{2n+2} + nH_2O.$$

The out coming hot gaseous mixture is cooled in a cooler where a liquid resembling crude oil is obtained which is then subjected to fractionation to yield gasoline and heavy oil. The heavy oil is reused for cracking to get more gasoline.



ii) Bergius Process:- Coal is powdered and made into a paste with heavy oil and a catalyst is mixed with it. This mixture is sent to a converter maintaining at 400-500°c and a pressure of 200-250atm, where it meets the hydrogen. Hydrogenation takes place to form higher hydrocarbons. These are further decomposed to produce lower hydrocarbons. When these lower hydrocarbons are passed through a cooler, a liquid resembling crude oil is obtained. This oil on fractional distillation gives gasoline, middle oil and heavy oil. The middle oil is subjected to hydrogenation in presence of a catalyst to produce more gasoline. The heavy oil is recycled to make a paste with fresh coal powder.



Knocking: Knocking is a kind of explosion due to rapid pressure rise occuring in an IC engine. The knocking tendency decreses in the following order.

Straight chain paraffins > Branched chain paraffins > Cycloparaffins > Olefins > Aromatics.

Octane number: The percentage of iso octane present in a mixture of iso octane and n-heptane which has the same knocking characteristics as the gasoline (Petrol) sample under test.

Cetane number: The percentage of hexa decane present in a mixture of hexa decane and 2- methyl naphthalene, which has the same knocking characteristics as the diesel sample under test.

Power alcohol: When ethyl alcohol is used as an additive to motor fuels to act as a fuel for internal combustion engines, it is called power alcohol.

Manufacture of power alcohol: The important raw materials for manufacture of power alcohol or ethyl alcohol are saccharine materials such as molasses, sugar beets etc. Starch materials such as starch, potatoes, cereal grains etc.

Ethyl alcohol from molasses: A Formentation process is used for manufacture of ethyl alcohol from molasses. It is a dark colored viscous liquid left after crystalization of cane sugar from cane juice. It contains 20-30% of sugar. Molasses is converted in to ethyl alcohol by means of yeast, which gives invertse and zymase responsible for fermentation. Before mixing with yeast, the molasses is dilutd with water; P^H is maintained between 4 – 5, at 30^0C by adding sulphuric acid. Fermentation is completed between 2 to 3 days. Repeated distillation and condo nation can raise the alcohol content to 97.6%

$$C_{12}H_{22}O_{11} + H_2O \text{ ----------> } C_6H_{12}O_6 + C_6H_{12}O_6$$

$$C_6H_{12}O_6 \text{ ----------> } 2C_2H_5OH + 2CO_2 \text{ (g)}$$

Advantages:

1. Addition of power alcohol to petrol increases the octane number. Hence alcohol blend petrol possesses better antiknock properties.
2. There are no starting difficulties with alcohol petrol blend.
3. Alcohol bended petrol can be used in engines with higher compression.

Disadvantages:

1. Alcohol is easily oxidised to acids. Hence alcohol may cause corrosion.
2. Alcohol lowers the calorific value of petrol.

Calorific Value:- The efficiency of fuel is expressed in terms of calorific value. Calorific value of a fuel is defined as the total quantity of heat liberated by burning a unit mass or volume of fuel completely.

Types of calorific value:

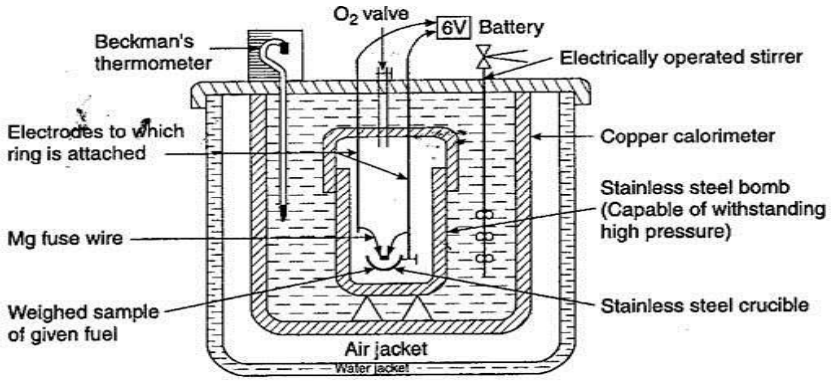
Gross calorific value: The total amount of heat liberated when a unit mass of the fuel is completely burnt and the products of combustion are cooled down to room temperature is called gross calorific value.

$$GCV \text{ (or) } HCV = (W+w)(t_2 - t_1) / m \quad cal/g.$$

Net calorific value: The amount of heat liberated when a unit of fuel is completely burnt and the combustion products are allowed to escape is called net calorific value.

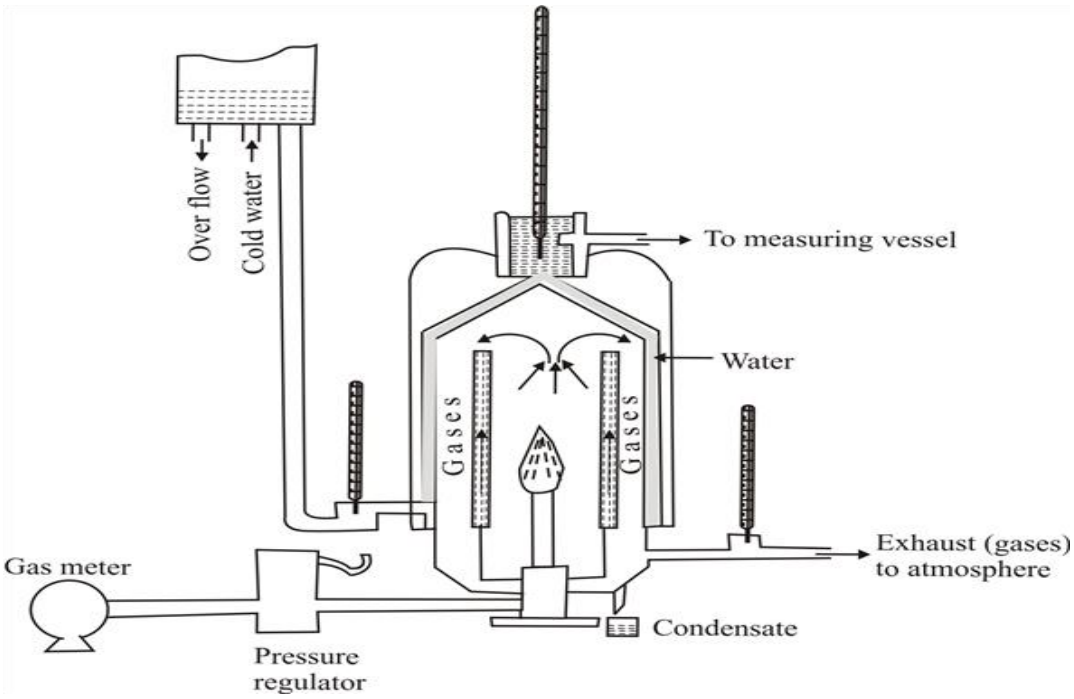
$$NCV \text{ (or) } LCV = GCV - 0.09 \times H \times 587$$

Determination Of Calorific Value By Bomb Calorimeter:- Calorific value of solid and non-volatile liquid fuels is determined by using bomb calorimeter. The apparatus consists of a cylindrical stainless steel bomb in which the combustion of fuel takes place. The bomb has a gas tight screw cap to which a couple of stainless steel electrodes, an oxygen inlet valve and a pressure releases valve are fitted. A crucible is supported by a ring attached to one of the electrodes. The bomb is placed in a copper calorimeter which is surrounded by an air jacket and other water jacket to prevent heat loss due to radiation. The calorimeter is provided with an electrically operated stirrer and a Beckmann thermometer to measure the rise in temperature.



Procedure:- About 0.5 to 1.0 gm of air dried fuel is taken in the clean crucible which is supported over the ring. A fine magnesium fuse wire is placed on the fuel sample and stretched across the electrodes. About 10 ml of water is filled in the bomb to absorb any vapours. The bomb lid is tightly screwed and the bomb is filled with oxygen gas up to 25 atm pressure. The bomb is then lowered into the calorimeter containing a known mass of water. The stirrer is worked and initial temp of the water is noted. The stirrer is worked and initial temp of the water is noted. The electrodes of the bomb are connected to a 6 volts battery and circuit is completed. The fuel burns and heat is liberated. The temp of water gradually increases with uniform stirring and attained maximum temperature is noted.

Determination of Calorific Value By Junkers Gas Calorimeter:- The calorific value of gaseous and volatile liquid fuels is measured by using an apparatus known as Junkers gas calorimeter. The equipment consists of pressure governor, gas flow meter, Bunsen burner, calorimeter, etc,. The calorimeter is fixed on a tripod stand having levelling screws to keep the calorimeter in perfectly vertical position. The calorimeter mainly consists of a gas combustion chamber, heat exchanger and water flow system. The entire system is covered by an outer jet in order to reduce the heat loss by radiation and convection. Two thermometers are used to record the temp of inlet water and outlet water respectively. Water enters into the calorimeter through a constant heat and its temp is noted.



Procedure: The sample of gas whose calorific value is to be determined passes through a pressure governor, and then through gas flow meter and finally burns in Bunsen burner. The hot products of combustion move upward in the chamber, then downward and finally escape through the exit where its temp is measured. The heat generated by combustion of gas is absorbed by the circulated cold water. When the steady conditions are established, then the volume of gaseous fuel burnt, the weight of the water circulated, the steady rise in temp are recorded.

Problems on Bomb calorimeter:

1. Calculate the gross and net calorific value of a coal sample from the following data obtained from bomb calorimeter. Weight of coal 0.73 g, weight of water in the calorimeter 1500 g, water equivalent in calorimeter 470 g, initial temp 25 ^{0}C and final temp 28^{0}C, percentage of hydrogen in

coal 2.5% and latent heat of steam 587 cal/g.

Solution: The given data

m= 0.73 g, W = 1500 g, w= 470 g, t_1 = 25^{0}C t_2 =28^{0}C, % of hydrogen = 2.5%, Latent heat of steam= 587 cal/g.

Gross calorific value (GCV) = (W+w) ($t_2 - t_1$) / m cal/g.

= (1500+470) (28-25) / 0.73

= 8095.89 cal/g.

Net calorific value (NCV) = GCV- 0.09 × H × 587

= 8095.89 – 0.09 × 2.5 × 587

= 7963.82 cal/g.

Gaseous Fuels:-

Advantages:-

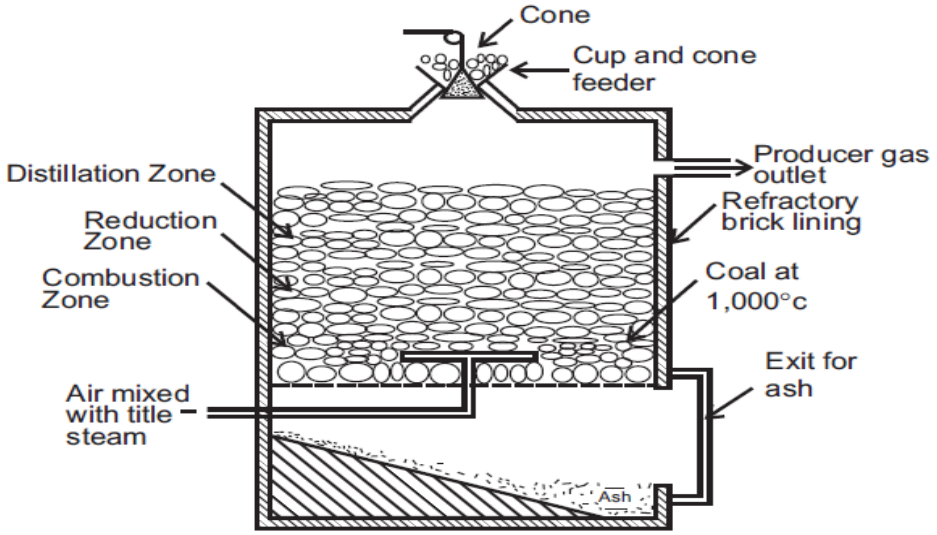
- Their combustion can be controlled.
- They possess high calorific value.
- They easily transport through pipe lines.
- They require less amount of air for complete combustion.
- They burn without smoke and produce no ash.

Disadvantages:-

- They are highly inflammable.
- They require very large storage tanks.
- They are cost than solid & liquid fuels.

Types of Gaseous fuels:

Water gas: It is a mixture of combustible gases, CO(41%) and H_2 (51%) with small amount of non-combustible gases, CO_2(4%) and N_2(4%). Its calorific value is about 2800 kcal/m^3.



Gas Producer

Manufacture

The water gas producer consists of a tall steel vessel, lined inside with refractory bricks. It is provided with cup and cone feeder at the top and a side opening for water gas exit. At the bottom it is provided with two inlet pipes for passing air and steam. When steam and little air is passed alternatively over a red hot coke maintained at about 900 - l000°C in a reactor, water gas is produced.

Reactions

The reaction of water gas production involves the following two steps.

Step 1

In the first step, steam is passed through the red hot coke, where CO & H2 gases are produced. The reaction is endothermic. Hence, the temperature of the coke bed falls.

$C + H_2O \longrightarrow CO + H_2$ endothermic – 29 k cal

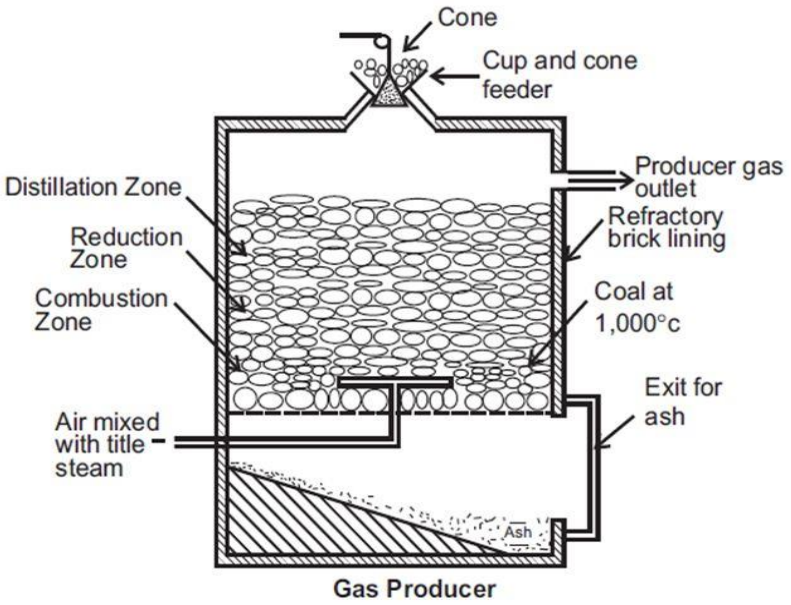
Step 2

In the second step, in order to raise the temperature of the coke bed to 1000 C , the steam supply is temporarily cut off and air is blown in. The reaction is exothermic.

$C + O_2$ ----------> CO_2 Exothermic +95 k cal

Uses: It is used for the production of H2 and in the synthesis of ammonia. It is also used as a source of and illuminating gas and fuel gas.

Producer Gas: Producer gas is a mixture of combustible gases, CO(30%) and H_2(15%) with large amount of non combustible gases N_2(56%) and CO_2(3%). Its calorific value is 1300kcal/m3.It is prepared by passing air mixed with a little steam over a red hot coke maintained at about l100°C in a special reactor called gas producer. It consists of a steel vessel of (3 m in diameter, 4f m in height) inside lined with refractory bricks. It is provided with cup and cone feeder at the top and a side opening for produced gas exit. At the bottom, it has inlets for passing air and steam.



Manufacture of Producer Gas

17

Various Reactions

The reactions of producer gas production can be divided into four zones as follows.

(i) Ash Zone

This is the lowest zone consists mainly of ash. The incoming air and steam mixture is preheated in this zone.

(ii) Combustion or Oxidation Zone

This is the zone next to ash zone. Here the coke is oxidised to CO and CO_2. Both the reactions are exothermic. Hence, the temperature of the bed reaches around 1,100°C.

$C + O_2$ ----------> CO_2 Exothermic +95 k cal

(iii) Reduction Zone

This is the middle zone. Here both CO_2 and steam combine with red hot coke and liberate H_2 and CO. The reduction reactions are endothermic and the temperature in the zone is about 1000°C. If no steam is supplied, the temperature of the producer raise and this may fuse the ash and refractory lining.

$$C + H_2O \longrightarrow CO + H_2 \qquad \text{endothermic} - 29 \text{ k cal}$$

(iv) Distillation or Drying Zone

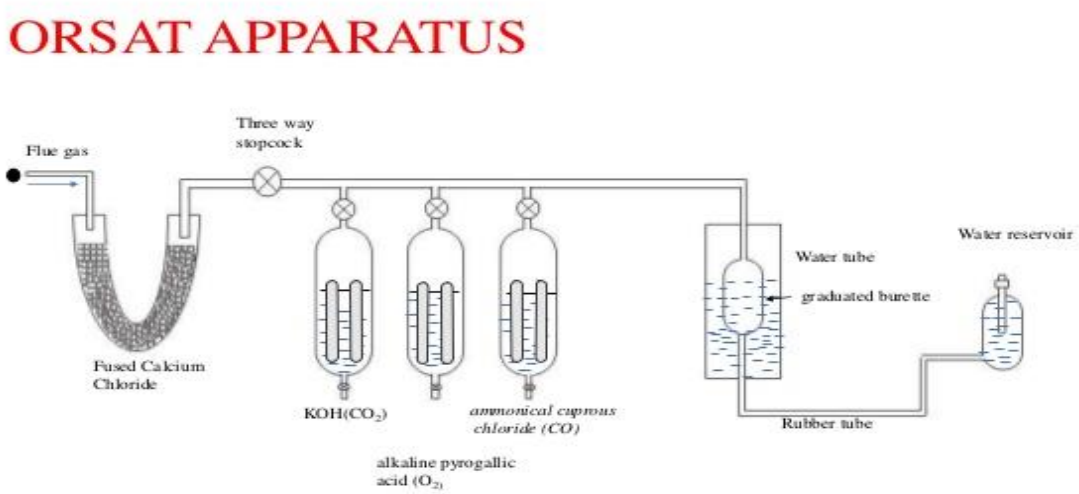
In this zone (400 - 800°C) the down coming coal is heated by the outgoing gases. The heat given by the gases and the heat coming out from the reduction zone will distil the fuel.

Uses

1. It is used as a reducing agent in metallurgical operations.

2. It is also used for heating muffle furnaces, open-hearth furnaces etc.

FUEL GAS ANALYSIS BY ORSAT 'S APPARATUS:- The efficiency can be determined experimentally by the analysis of the flue gas coming out from the combustion chamber. Flue gas is mainly the mixture of Co_2, CO and O_2. Flue gas analysis is carried out by using Orsat 's apparatus. It consists of a horizontal tube provided with a three way stop cock at one end and 100ml graduated burette at the other end which is surrounded by a water jacket to keep the temp of gas constant during the experiment. 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 with the help of water reservoir. The horizontal tube is also connected with three different absorption bulbs (A, B and C) A bulb contains potassium hydroxide which can absorb Co_2, B bulb contains alkaline pyrogallol which can absorb Co_2 and O_2, C bulb contains ammoniacal cuprous chloride which can absorb Co_2, Co and O_2. Hence it is necessary that fiue gas is passed first through A bulb where Co_2 is absorbed, then through B bulb where only O_2 is absorbed and finally through C bulb where only Co is absorbed.



Procedure:- The apparatus is cleaned and the absorption bulbs are filled with respective solutions and their stop cocks are closed. The three way stop cock is opened to the atmosphere, then the reservoir is raised till the burette is completely filled with water and air is completely removed from the tube and burette. The flue gas is sucked into the burette and the volume is adjusted to 100 ml.

- The stop cock of the blub A is opened and the water reservoir is raised to force the gas inside the bulb. The KOH solution absorbs Co_2. The gas is again passed to the burette. The process is continued until the complete absorption of Co_2 and stop cock of A is closed. The decrease in volume of flue gas gives the volume of Co_2 in 100 ml of flue gas.
- The stop cock bulb B is opened where O_2 of flue gas is absorbed. The decrease in volume of the gas gives the volume of O_2 and stop cock of bulb B closed.
- Finally the stop cock of bulb C is opened where CO is absorbed. The decrease in volume of flue gas gives the volume of Co.

The volumes of O_2 and Co are measured using the same process of Co_2. The remaining gas in burette after absorption of Co_2, O_2 and CO is taken as nitrogen.

SIGNIFICANCE:- From the flue gas analysis, it is possible to know whether the fuel is burnt completely or not.

i) If the flue gas contains high percentage of CO, it indicates incomplete combustion and oxygen supply is less than required amount.

ii) If there is high percentage of O_2 in flue gas, it indicates complete combustion and oxygen supply is more than required amount.

Combustion:- Combustion process is an exothermic chemical reaction which is accompanied by heat and light. In other words, it is the union of an element or substance with oxygen. During combustion, the combustible substance or element when brought to their ignition temp, burn in presence of air(O_2) instantly with the development of heat and there is a considerable increase in temperature.

Important Questions:

1. How is metallurgical coke manufactured by Otto Hoffmann's by product oven process? Discuss the various by products formed during the process.
2. What is coal? Explain proximate and ultimate analysis of coal.
3. Explain classification of coal. Write advantages & disadvantages of coal?
4. Explain the manufacture of synthetic petrol by Fischer tropsch and Bergius process with neat diagram.
5. Describe the method employed for the refining of crude oil with diagram.
6. What is power alcohol? Discuss the manufacturing process of power alcohol.
7. What is flue gas? Explain analysis of flue gas by Orsats gas apparatus.
8. Explain preparation, composition and uses of water gas / Producer gas / Bio gas / Coal gas.
9. On burning 0.83 g of a solid fuel in a bomb calorimeter, the temperature of 3500 g of water increased from 25.5^0c to 29.2^0c. Water equivalent of calorimeter is 385 g and latent heat of steam is 587cal/g. Calculate the gross and net calorific values if percentage of hydrogen in fuel is 0.7%.
10. A sample of coal contains the following composition: C=72%, H_2= 6.2%, O_2= 14.8%, S= 1.6%, N_2= 2.8% and ash is 2.6%. Calculate the minimum amount of air required for complete combustion of 1 kg of coal and give the percentage composition of dry products of combustion.