UNIT-IV FUELS AND COMBUSTION

1.WHAT IS PROXIMATE ANALYSIS ? WRITE ITS SIGNIFICANCE.

It is the analysis involving the determination of physical constituents like percentage of

- Moisture content
- Volatile matter
- Ash content
- Fixed carbon in coal

I. Moisture content:

About 1 gm of finely powdered air dried coal sample is weighed in a crucible. This is then placed in an air-oven maintained at 105^{o}C – 110^{o}C. After 1 hr. the crucible is taken out, cooled in a desiccator and weighed. Loss in weight gives the moisture content.

$$\% \text{ of Moisture content in coal} = \frac{\text{Loss in weight of the coal sample}}{\text{Weight of air-dried coal}}$$

Significance:

High percentage of moisture is undesirable because

(i) It reduces the calorific value of coal,
(ii) It increases the transport Cost
(iii) Produces smoke

II. Volatile matter:

After the analysis of moisture content, the residual coal sample in the crucible is then covered with a lid and placed in a muffle furnace maintained at 950^{o}C $\pm$ 20^{o}C. The crucible is taken out of the oven after 7 minutes of heating. The crucible is cooled first in air, then inside a desiccator and weighed again. The loss in weight will give the volatile matter.

$$\% \text{ of volatile matter in coal} = \frac{\text{Loss in weight of the coal sample}}{\text{Weight of air-dried coal}}$$

Significance:

High percentage of volatile matter is undesirable because

(i) It reduces the calorific value of coal,
(ii) Produces sooty and smoky flame

III. Ash Content:

After the analysis of volatile matter, the residual coal sample in the crucible is heated without lid in a muffle furnace at 700 $\pm$ 50^{o}C for half an hour. The crucible is then taken out, cooled first in air, then in a desiccator and weighed.

Heating, cooling and weighing is repeated till a constant weight is obtained. The residue is ash.

$$\% \text{ of volatile matter in coal} = \frac{\text{Loss in weight of the coal sample}}{\text{Weight of air-dried coal}}$$

Significance:

High percentage of ash content is undesirable because

(i) It reduces the calorific value of coal
(ii) Ash causes clinkers, which disturbing the oxygen supply
(iii) Forms flying ash which causes air and land pollution

IV. Fixed carbon:

It is determined by subtracting the sum total of moisture, volatile and ash content, as percentage from **100**.

%of fixed carbon in coal=100%-[moisture content +volatile matter + ash]

Significance:

High percentage of fixed carbon is desirable because

(i) Higher the percentage of fixed carbon in a coal, greater is its calorific value,
(ii) The percentage of fixed carbon helps in designing the furnace

2. EXPLAIN THE ULTIMATE ANALYSIS PROCESS AND WRITE ITS SIGNIFICANCE

Ultimate analysis refers the determination of chemical constituents like % of Carbon, Hydrogen, Sulfur, ash and oxygen content.

I. CARBON AND HYDROGEN CONTENTS

A known amount of the coal sample is burnt in a current of O_2 in a combustion apparatus. The Carbon and hydrogen, present in the coal sample, are converted into CO_2 and H_2O respectively according to the following equations.

$$c + o_2 \rightarrow co_2 \uparrow$$

$$H_2 + 1/2O_2 \rightarrow H_2O \uparrow$$

The liberated CO_2 & H_2O vapours are adsorbed respectively in KOH & anhydrous $CaCl_2$ tube of known weights.

- The increase in weight of KOH tube is due to the formation of CO_2
- Increase in weight of $CaCl_2$ tube is due to the formation of H_2O

Form the weights of CO_2 and H_2O formed, the % of C & H present in the coal can be calculated as follows:

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

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

$$\textbf{\% of Carbon in coal} = \frac{\textbf{Increase in weight of KOH tube} \times \textbf{12}}{\textbf{Weight of coal Sample taken} \quad \textbf{44}} \times \textbf{100}$$

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

Significance:

(i) Higher the % of carbon and hydrogen, better is the quality of coal and higher is its calorific value.

(ii) Higher % of carbon in coal reduces the size of combustion chamber required.

II. NITROGEN CONTENT:

The determination of N_2 content is carried out by Kjeldahl's method

The determination of nitrogen content is carried out by Kjelda'hsl method. A known amount of powdered coal sample is heated with con. H_2SO_4 in presence of K_2SO_4 (catalyst) in a long necked flask (called Kjeldahl's flask). Nitrogen in the coal is converted into ammonium sulphate and a clear solution is obtained.

$$2N + 3H_2 + H_2SO_4 \xrightarrow{\Delta} (NH_4)_2 SO_4 \text{ [Ammonium Sulphate (clear solution)]}$$

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

$$(NH_4)_2SO_4 + 2NaOH \xrightarrow{\Delta} 2NH_3 + Na_2SO_4 + 2H_2O$$

The liberated ammonia is distilled over and is absorbed in a known volume of standard N/10 HCL.

$$NH_3 + HCl \longrightarrow NH_4C$$

The volume of unused N/10 HCl is then determined by titrating it against standard N/10 NaOH. Thus the amount of acid neutralized by liberated ammonia from coal is determined.

From this the percentage of N_2 is calculated

$$\textbf{\% of } N_2 \textbf{ in coal} = \frac{\textbf{14 X volume of acid consumed X Normality X 100}}{\textbf{1000 X Weight of coal sample}}$$

Significance:

(i) Nitrogen does not have any calorific value, and its presence in coal is undesirable.

(ii) Good quality coal should have very little nitrogen content.

III SULPHUR CONTENT.

A known amount of coal sample is burnt completely in bomb calorimeter. During the process sulphur is converted into sulphate, which is extracted with water. The extract is then treated with $BaCl_2$ solution so that sulphates are precipitated as $BaSO_4$. The precipitate is filtered, dried and weighed.

$$S + 2O_2 \rightarrow SO_4^{2-} \xrightarrow{BaCl_2} BaSO_4 \downarrow$$

(Barium sulphate precipitate)

From the weight of $BaSO_4$ obtained, the sulphur present in the coal is calculated.

$$\textbf{\% of S in coal} = \frac{\textbf{32 X weight of } BaSO_4 \textbf{ obtained X 100}}{\textbf{233 X weight of coal sample}}$$

Significance:

Its presence in coal is undesirable because

(i) The combustion products of sulphur, i.e., SO_2 and SO_3 are toxic and have corrosion effects on equipment's.

(ii) The coal containing sulphur is not suitable for the preparation of metallurgical coke as it affects the properties of the metal.

IV. ASH CONTENT:

It is the weight of residue obtained after burning a known weight of coal in an open crucible in the presence of air at 750 °C for 30 minutes.

$$\% \text{ of ash in coal} = \frac{\text{Weight of ash formed X100}}{\text{Weight of dried coal}}$$

Significance:

High percentage of ash content is undesirable because

(i) It reduces the calorific value of coal

(ii) Ash causes clinkers, which disturbing the oxygen supply

(iii) Forms flying ash which causes air and land pollution

V. OXYGEN CONTENT.

The percentage of oxygen is calculated as follows.

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

Significance:

(i) Lower the % of oxygen higher is its calorific value.

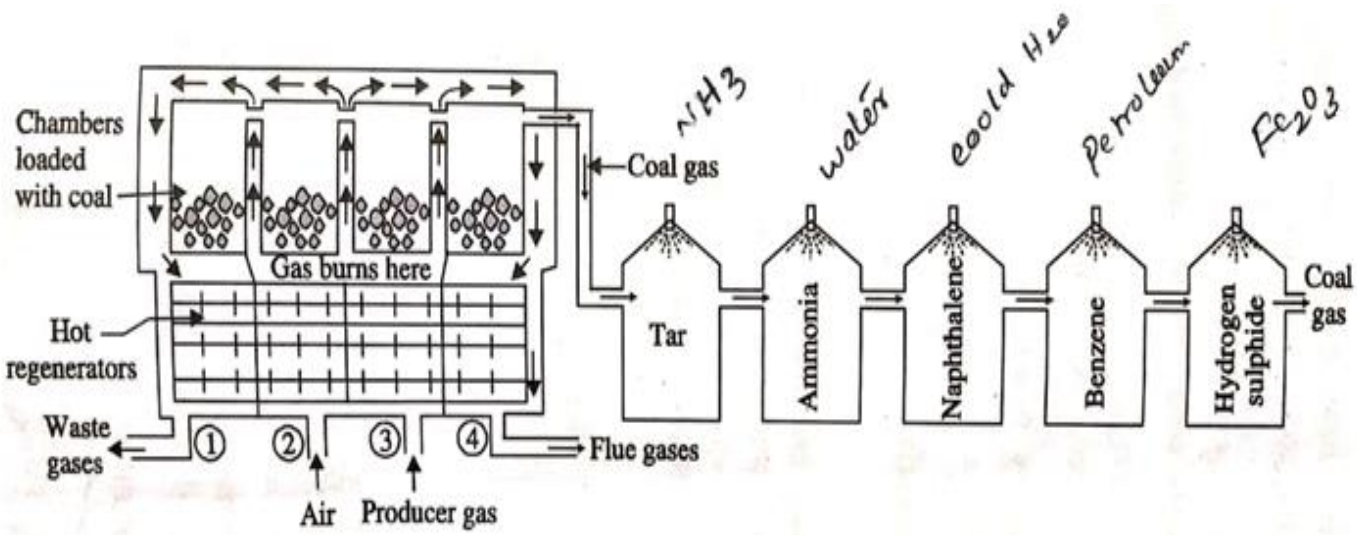
(ii) As the oxygen content increases its moisture holding capacity increases, and the calorific value of the fuel is reduced.

3. DESCRIBE THE OTTO HOFFMAN PROCESS FOR THE MANUFACTURE OF METALLURGICAL COKE.

There are so many types of ovens used for the manufacture of metallurgical coke. But the important one is Otto-Hoffman's by product oven.

Objectives & Advantages

- Increase the thermal efficiency of the carbonization process and
- Recover the valuable by products like Tar, Ammonia, Naphthalene, Benzene, H_2S and coal gas



Time taken for complete combustion=12-20 hours

Yield of coke=70

DESCRIPTION OF OTTO HOFFMAN'S BY PRODUCT OVEN:

The oven consists of a number of silica chambers each chamber is about 10 -12m long, 3-4m in height and 0.4-0.45m wide. Each chamber is provided with a charging hole, gas off take value and iron door for discharging coke.

Working:

1. Coal is introduced into the silica chamber and the chambers are closed. The chambers are heated to 1200°C by burning the preheated air and the producer gas mixture in the interspaces between the chambers.
2. The air and gas are preheated by sending them through 2nd and 3rd regenerators. Hot flue gases produced during carbonisation are allowed to pass through 1st and 4th hot regenerators until the temperature has been raised to 1000°C. While the 1st and 4th regenerators are heated by hot flue gases, 2nd and 3rd regenerators are used for heating the incoming air and gas mixture.
3. For economical heating, the direction of inlet gases and flue gases are changed frequently. The above system of recycling the flue gases to produce heat energy is known as the regenerative system of heat economy. When the process is complete the coke is removed and quenched with water.
4. Time taken for complete carbonisation is about 12 -20 hours. The yield of coke is about 70%.The valuable by products like coal gas, tar, ammonia, H_2S and benzol, etc. can be recovered from flue gas.

Recovery of by- products:

BY PRODUCTS	CHEMICALS USED FOR RECOVERY
Tar	Tar is recovered by spraying liquid ammonia
Ammonia	Ammonia is recovered by spraying water and forming NH_4OH
Naphthalene	Naphthalene is recovered by spraying cool water
Benzene	Benzene is recovered by spraying petroleum
Hydrogen sulphide.	H_2S is recovered by passing through moist Fe_2O_3.
Gaseous fuel	The final gas left out is called coal gas which is used as a gaseous fuel.

ADVANTAGES:

- valuable by-products are recovered
- carbonization time is less
- Heating is done extremely by producer gas.

4. GIVE A BRIEF ACCOUNT OF REFINING OF PETROLEUM AND THE PRODUCTS OBTAINED AND THEIR USES.

DEFINITION:

The process of removing impurities and separating the crude oil into various fractions having different boiling points is called refining of petroleum.

The process of refining involves the following steps:

STEP 1: SEPARATION OF WATER:

The crude oil is allowed to flow between two highly charged electrodes, where colloidal water droplets combine to form large drops, which is then separated out from the oil.

STEP 2: REMOVAL OF HARMFUL SULPHUR COMPOUNDS:

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

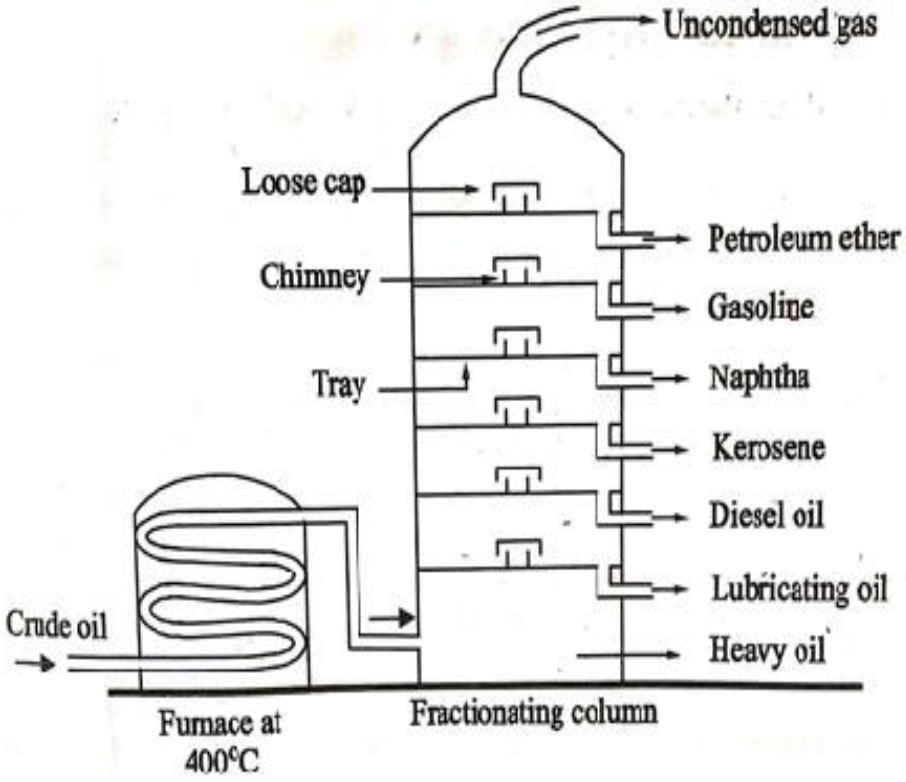
Crude oil + Copper oxide ⟶ Copper sulphide

(Separated out by filtration)

STEP 3: FRACTIONAL DISTILLATION:

Description

The fractionating column is a tall cylindrical tower containing a number of horizontal stainless steel trays at short distances. Each tray is provided with small chimney covered with loose cap.



Working:

- The purified crude oil is heated to about 400°C in an iron retort, where the oil gets vaporized. The hot vapours are then passed into the bottom of a "Fractionating column".
- When the vapours of the oil go up in the fractionating column, they become cooler and get condensed at different trays.
- The fractions having higher boiling points condense at lower trays.
- The fractions having lower boiling points condense at higher trays.
- The gasoline obtained by this method is called straight-run gasoline.

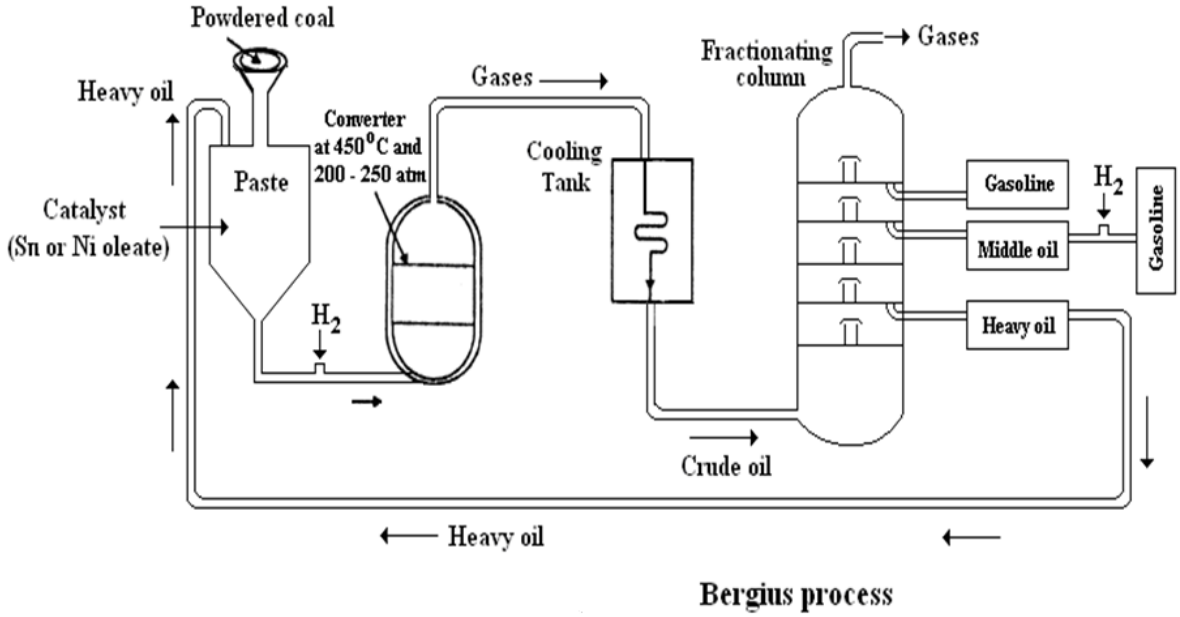
5. WHAT IS SYNTHETIC PETROL? HOW IS IT MANUFACTURED BY BERGIUS PROCESS?

The gasoline, obtained from the fractional distillation of crude petroleum oil, is called straight run petrol. As the use of gasoline is increased, the amount of straight run gasoline is not enough to meet the requirement of the present community. Hence, we are in need of finding out a method of Synthesizing petrol

Hydrogenation of coal (or) Synthetic petrol

Coal contains about 4.5% hydrogen compared to about 18% in petroleum. So coal is a Hydrogen deficient compound. If coal is heated with hydrogen to high temperature under high pressure, it is converted to gasoline. The preparation of liquid fuels from solid coal is called **Hydrogenation of coal (or) synthetic petrol.**

Bergius process:



Bergius process

Bergius process (or) direct method

1. In this process, the finely powdered coal is made into a paste with heavy oil and a catalyst powder (tin or nickel oleate) is mixed with it.
2. The paste is pumped along with hydrogen gas into the converter, where the paste is heated to 400 − 450°C under a pressure of 200 − 250 atm.
3. During this process hydrogen combines with coal to form saturated higher hydrocarbons, which undergo further decomposition at higher temperature to yield mixture of lower hydrocarbons.
4. The mixture is led to a condenser, where the crude oil is obtained.
5. The crude oil is then fractionated to yield (i) Gasoline (ii) Middle oil (iii) Heavy oil.
6. The middle oil is further hydrogenated in vapour phase to yield more gasoline. The heavy oil is recycled for making paste with fresh coal dust.
7. The yield of gasoline is about 60% of the coal used.

6. EXPLAIN IN DETAIL ABOUT KNOCKING AND SUGGEST WAYS TO AVOID THEM.

KNOCKING (Definition):

Knocking is a kind of explosion or unwanted sound due to rapid pressure in an IC engine.

MECHANISM OF KNOCKING:

- The fuel in petrol engines is **g**asoline and **a**ir mixed in 1:17 ratio.
- The mixture is compressed and ignited by an electric spark. The products of combustion (oxidation) reaction increases the pressure and pushes the piston down the cylinder.
- If the combustion proceeds in a regular way, there is no problem in knocking. But in some cases, the rate of combustion (oxidation) will not be uniform due to unwanted chemical constituents of gasoline.
- The rate of ignition of the fuel gradually increases and the final portion of the fuel-air mixture gets ignited instantaneously producing an explosion sound known as knocking
- Knocking property of the fuel reduces the efficiency of engine.
- So a good gasoline, should resist knocking

CAUSES OF KNOCKING:

- The knowking tendency of fuel hydrocarbons mainly depends on their chemical structure

  The knocking tendency decreases in the following order:-

  Straight chain paraffins > branched chain paraffins > cyclo paraffins > aromatics

EFFECTS OF KNOCKING:

- It reduces the efficiency of IC engines
- It damages the cylinder or piston

KNOCKING CAN BE REDUCED BY:

- Adjusting engine design and operating conditions(i.e. compression ratio or burning time)
- Use of gasoline of higher octane number (use of anti-knock agents)

7. WHAT IS OCTANE NUMBER? DETAIL ANSWER.

Octane number is introduced to express the knocking characteristics of petrol. It has been found that n-heptane knocks very badly and hence, its anti-knock value has been given 0. On the other hand, iso-octane gives very little knocking and so, its anti-knock value has been given 100

Octane number is defined as 'the percentage of iso-octane present in a mixture of iso-octane and n-heptane' Octane numbers are based on a scale on which the octane number of isooctane is 100 and heptane is 0.

HOW TO IMPROVE THE OCTANE NUMBER OR THE ANTI-KNOCKING PROPERTIES OF GASOLINE?

- By use of alkanes with branching chains rather than straight chains.
- By use of aromatic alkanes (with rings).
- By addition of anti-knock agents like tetra -ethyl lead (TEL)
- By use of aromatic phosphates instead of TEL thus avoiding pollution due to lead.
- By blending gasoline or petrol of high octane number with petrol of low octane number

MECHANISM OF ANTI-KNOCKING BY TEL:

- Knocking occurs due to formation of free radicals from the molecules of fuel mixture.
- The free radicals initiate localized growths, and an imbalance in fuel mixture causes knocking
- TEL is thermally decomposed to form ethyl free radical which helps for termination of free radicals.
- This helps for stopping the knocking in IC engines.

DISADVANTAGES OF TEL:

- The leaded petrol contains tetra-ethyl lead (TEL) as the anti-knocking agent.
- During combustion lead (Pb or PbO) is released from TEL
- Pb or PbO deposit on the cylinder walls and spark plug.
- This affects the engine reducing its efficiency and life time.

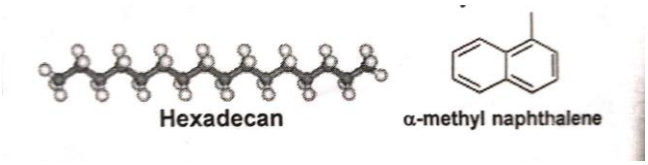
LEAD SCAVENGERS:

- Lead scavengers can be added with TEL
- The scavengers react with Pb and escapes as its volatile compounds; for example, ethylene bromide which is used as a Pb-scavenger, allows Pb to escape as $PbBr_2$ gas.
- But the lead scavengers cause atmospheric pollution. So now a days aromatic phosphates are used instead of TEL.

8. WHAT IS CETANE NUMBER? EXPLAIN IN DETAIL.

Cetane number is a rating on a scale used to indicate how quickly a fuel will ignite in a diesel engine.

It is the percentage of hexadecane present in a mixture of hexadecane and α-methyl naphthalene, which has the same ignition delay as the fuel under study.



MECHANISM OF KNOCKING IN DIESEL ENGINE:

- In the diesel engine, the fuel is ignited by hot air.
- The air is heated by compression
- The fuel is injected into this hot air just before the piston reaches top center
- 'Top center' is the moment when the piston has travelled into the cylinder as far it can go and compression is at a maximum.
- Ideally, ignition should begin just as the piston reaches the top center.
- If it does not the entire charge of fuel has time to become thoroughly mixed with air
- When ignition takes place after the mixing, the pressure rise is much steeper and cause knocking.

EFFECTS OF LOWER CETANE NO.

- It will be harder to start such diesel engines, and the engines gives more emissions.
- Much noise will be produced and the engine operated roughly.

SIGNIFICANCE OF LOWER CETANE NO.

- It denotes the combustion quality of diesel fuel during compression ignition.
- It determines the overall diesel quality.

RELATIVE CETANE RATINGS:

Straight chain paraffin>branched chain paraffin> Cyclo paraffin > olefins> branched paraffin> Aromatics.

DOPING FOR INCREASING CETANE NUMBER:

- The cetane number can be increased by doping.
- Doping can be done by addition of ethyl nitrate or 2-ethylhexyl nitrate or iso-amyl nitrate.

9. WHAT IS POWER ALCOHOL? GIVE ITS ADVANTANGES AND DISADVANTAGES.

- When Ethyl alcohol is blended with petrol at concentration of 5-10% it is called power alcohol.
- Absolute alcohol (100% pure) is also called power alcohol.
- Addition of ethyl alcohol to petrol increases its octane number. Power alcohol is used as fuel for IC engines.

MANUFACTURE:

STEP 1: Ethyl alcohol is prepared by fermentation of molasses obtained from sugar industries.

$$C_6H_{12}O_6 \xrightarrow[\text{Yeast}]{} 2C_2H_5OH + 2CO_2$$

STEP 2:

Ethyl alcohol in the ferment liquor is concentrated by fractional distillation (to get 97.6% alcohol). It is then distilled with benzene (or dehydrated with a dehydrating agent) to leave behind absolute alcohol

STEP 3:

Then absolute alcohol is mixed with petrol (so that the final mixture contains 5-10% absolute alcohol). The mixture is called absolute alcohol.

PROPERTIES OF POWER ALCOHOL:

- It has low calorific value (7000 kcal/kg)
- It has high octane number
- Its anti-knocking properties are good
- It generates 10% more power compared to same quantity of gasoline and its compression ratio is also high.

USES:

It is a very good motor fuel.

ADVANTAGES:

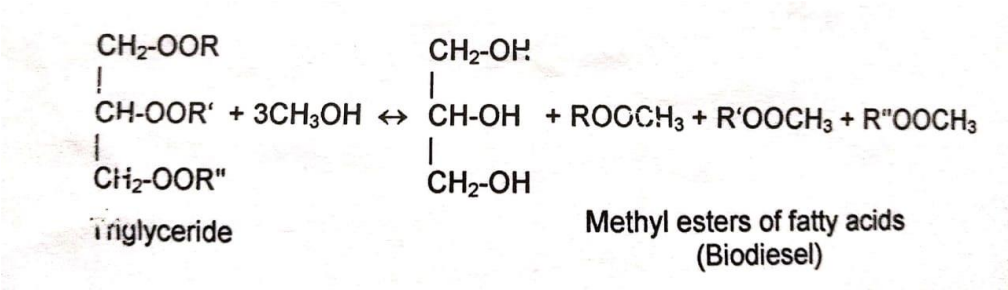
- Cheaper than petrol
- Absorbs moisture from the petrol and emission of CO, hydrocarbons and particulates are less.

DISADVANTAGES:

- Calorific value is less and engine design has to be different
- The amount of air required for combustion is less; hence engine and carburetor have to be modified.
- Output power is reduced up to 35%
- Due to high surface tension, starting trouble will be there, also it might get oxidized to acetic acid which can corrode engine parts.

10. BIO DIESEL:

Vegetable oil comprise 90-95% triglycerides. Triglycerides are esters of long chain fatty acids like stearic and palmitic acid. It has high viscosity (3 times higher than diesel). Triglycerides is converted into ' bio-diesel' by alcoholysis.



It is a pure fuel and can be blended with diesel.

PROBLEMS IN USING VEGETABLE OIL:

- Due to high viscosity, atomization is poor, hence insufficient mixing of oil and air leads to incomplete combustion.
- Oxidation and thermal polymerization causes deposit formation.
- High viscosity causes misfire and ignition lag.

ADVANTAGES OF BIO-DIESEL:

- It is biodegradable and renewable
- Causes less pollution
- It can be prepared from different vegetable oils.
- Gives best engine performance.

DISADVANTAES OF BIO-DIESEL:

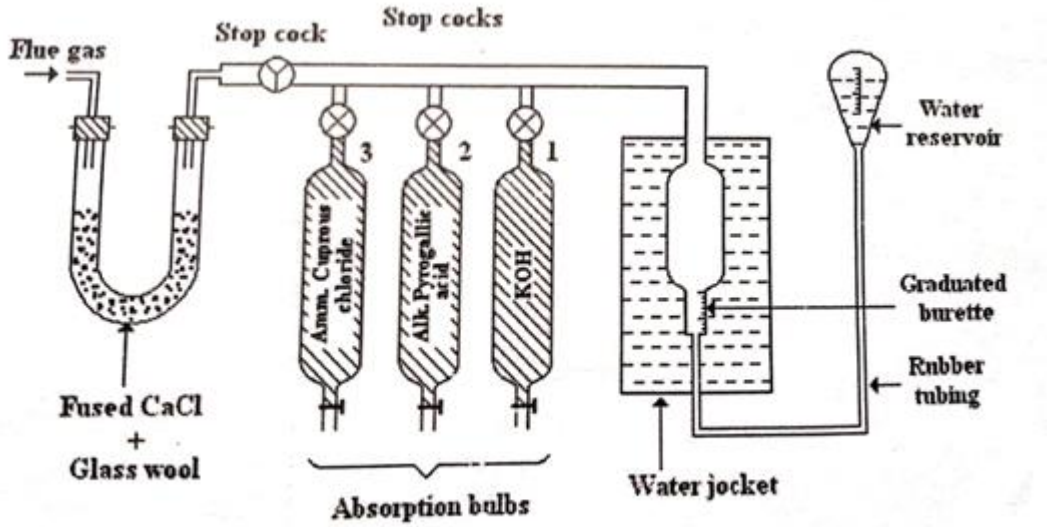
- It gets in cold weather
- It is hygroscopic; absorbs moisture
- It decreases the horse-power of engine
- It grades rubber and plastics
- It has 10% higher NO_x emission than petrol.

11. WHAT IS FLUE GAS? EXPLAIN IN DETAIL

Flue gas:

The mixture of gases (i.e. CO_2, O_2 and CO) coming out from the combustion chamber is called ' flue gases'.

The flue gas is analyzed using orsat apparatus



CONSTRUCTION OF ORSAT APPARATUS:

- Orsat's apparatus consists of a horizontal tube.
- One end of horizontal tube is connected to a U- tube containing fused $CaCl_2$ through a 3-way stopcock.
- The other end of the horizontal tube is connected to a burette which is surrounded by a water jacket to maintain constant temperature.
- The lower end of the burette is connected to a water reservoir by means of a rubber tube for level maintenance
- The horizontal tub is connected to three different adsorption bulbs each one having solution of KOH, alkaline pyrogallal and ammoniacal cuprous chloride.

ABSORBING SOLUTIONS:

- ✓ KOH
- ✓ ALKALINE PYROGALLAL
- ✓ AMMONIACAL CUPROUS CHLORIDE.

ORDER OF ABSORBANCE:

- ✓ 1st - CO_2(with KOH)
- ✓ 2nd -O_2 (with alkaline pyrogallal)
- ✓ 3rd -CO(with ammoniacal cuprous chloride)

EXPERIMENT:

I. Absorbance of CO_2:

- The stopper of the adsorption bulb-1, containing KOH solution is opened.
- All the flue gas in the burette is passed into bulb-1 by raising the water level in the burette.
- As the gas enters into the bulb -1, CO_2 present is absorbed. The gas is now withdrawn into the burette. This process is repeated several times to ensure complete adsorption of CO_2.
- The decrease in volume of flue gas in the burette indicates the volume of CO_2 present in the 100cc of the flue gas.

II.ABSORBANCE OF O_2:

- The stopcock of bulb-1 is closed and stopcock of bulb-2 is opened
- The gas is now sent into absorption bulb-2, where O_2 in the flue gas is absorbed.
- The process of sending the gas into the bulb and then withdrawing into the burette is repeated till all O_2in the flue gas is absorbed.
- The decrease in volume of the flue gas in the burette indicates the volume of O_2 presents in 100cc of the flue gas.

III.ABSORBANCE OF CO:

- The stopcock of bulb-2 is closed and stopcock of bulb-3 is opened.
- The gas is now sent absorption bulb-3, where CO in the flue gas is adsorbed
- The process of sending the gas into the bulb and then withdrawing into the burette is repeated till is repeated till all CO in the flue gas is adsorbed.
- The decrease in volume of the flue gas in the burette indicates the volume of CO present in 100cc of the flue gas.

SIGNIFICANCE OF FLUE GAS ANALYSIS:

- Flue gas analysis gives an idea about the complete or incomplete combustion process.
- If the flue gases contain considerable amount CO, it indicates incomplete combustion and supply of O_2.
- If the flue gases contain considerable amount of O_2, it indicates complete combustion and excess supply of O_2.

12. WRIT DETAILED NOTES ON CARBON EMISSION AND CARBON FOOTPRINT.

CARBON EMISSION

Definition:

It is defined as the release of carbon into the atmosphere. Since greenhouse gas emissions are often. Calculated as carbon dioxide equivalents, they are often referred to as "carbon emissions".

Source:

Burning of fossil fuels like coal, oil and natural gas are the primary sources due to the following activates.

(i) Transportation

(ii) Electricity production

(iii) Industry

(iv) Agriculture

(v) Land use and forestry

(vi) Commercial and residential

Reduction of carbon emission

Carbon emission can be reduced by reducing greenhouse gas emission. It can be done by the following ways.

1. In industry, green house gases can be reduced by many ways.

(i) Including energy efficiency

(ii) Fuel switching

(iii) Combined heat and power

(iv) Use of renewable energy

2. Avoid of using HFC's in refrigeration, air conditioning and foam blowing.

3. In oil and gas production, the leakage of green house gases can be controlled by reducing pressure from pipelines.

CARBON FOOTPRINT:

Definition:

It is the total amount of green house gases (including CO, and CH) that generated (emitted) by our direct and indirect activities.

Individual carbon footprint:

It is the sum total of their direct and indirect carbon emissions over the course of a year.

i.e.,Smaller your carbon footprint : better for the future

Bigger your carbon footprint: Have bigger negative impact in environment

The average carbon footprint for a person in united states is 16 tons. Globally, the average is closer to 4 tones. To avoid 2°C rise in global temperatures, the average global carbon footprint per year needs to drop under 2 tons by 2050.