FUELS AND COMBUSTION

Definition

Fuel is a combustible carbonaceous material which on proper burning in air gives large amount of heat that can be used economically for domestic and industrial purposes. Examples- wood, charcoal, coal, kerosene, petrol, diesel, producer gas, water gas, natural gas, etc.

NOTE:

- During the process of combustion, C and H of the fuel combine with oxygen of air to form CO_2 and H_2O respectively.
- Since the heat content of combustion products (CO_2, H_2O, etc.) being lower than that of   reactants (C, H, etc. of fuel), the chemical fuel release heat during their combustion process

Classification

• Based on their origin:

1) Primary (Natural) fuels

2) Secondary (Derived) fuels

These are again subdivided into solid, liquid and gaseous according to the physical state.

Classification of Fuels

Physical state	Primary fuel	Secondary Fuel
Solid	Wood, Peat, Coal, Lignite	Charcoal and coke
Liquid	Crude petroleum, vegetable oil	Petrol, Kerosene, Diesel, Synthetic petrol
Gas	Natural gas	Producer gas, water gas, Coal gas, Biogas, LPG

Fossil Fuels: Natural fuels that come from the remains of living things; fuels give off energy when they are burned.

Characteristics of a Good Fuel

- High calorific value.
- Moderate ignition temperature.
- Low moisture content
- Low content of non-combustible matter.
- In case of solid fuel, the ash content should be less and the size should be uniform.
- Moderate velocity of combustion
- Readily available in bulk at low cost.
- Products of combustion should not be harmful.
- Combustion should be easily controllable.
- It should be safe, convenient and economical for storage and transport

Calorific value

It is defined as "the amount of heat liberated when unit mass (or unit volume in the case of a gaseous fuel) of fuel is completely burnt in air or oxygen.

Units: Solid & Liquids-   Cal/g (CGS) or kcal/kg (MKS) or KJ/kg (SI)

Gaseous fuels – Cal/L (CGS), kcal/m3 (MKS) or J/m3 (SI)

 1 Cal/gm = 1.8 B Th U/lb. and 1kcal/m3 = 0.1077 B Th U/ft3

B Th U/lb. = British Thermal Unit per pound

B Th U/ft3 = British Thermal Unit per cubic feet

Gross or Higher calorific value (GCV/HCV)

It is defined as "the amount of heat liberated when unit mass / volume of the fuel is burnt completely in air and the products of <u>combustion are cooled to room temperature</u>."

Here, Fuel=> Hydrocarbon (compound of Carbon and Hydrogen)

Reactions $\quad C + O_2 \rightarrow CO_2 + heat \quad \& H_2 + \frac{1}{2} O_2 \rightarrow H_2O + heat$

Note: Since products are not escaped Therefore calorific values thus it is <u>Higher or Gross calorific value.</u>

Net or Lower calorific value (NCV/LCV)

It is defined as "the amount of heat produced when unit mass/volume of fuel is completely bunt in air and <u>the products of combustion are allowed to escape into the atmosphere</u>"

Here, heating done in open atmosphere, hot gases are allowed to escape into the environment. Hence the latent heat of water vapor is not included therefore.

NOTE: *Lower/net calorific value is less than GCV*

Relation between GCV and NCV

- GCV = NCV + Latent heat of condensation of steam

- NCV = GCV – Latent heat of condensation of steam

Since 18 parts of H2O has 2 parts of H therefore mass of Steam is 9 times mass of Hydrogen.

- **NCV = GCV –9 ×Mass of hydrogen × Latent heat of steam**

- **NCV = GCV – 0.09 × % of hydrogen × Latent heat of steam.**

(latent heat of steam = 587cal/g)

Determination of calorific value using Bomb Calorimeter

Principle:

- A known mass of the fuel sample is burnt completely in excess of oxygen.

- The liberated heat is absorbed by water and calorimeter.

- The heat lost by burning fuel is the heat gained by water and calorimeter.

- The calorific value of the fuel is calculated from the measured data.

Working of Bomb Calorimeter

• Known mass (0.5 to 1.0 g) of fuel taken in crucible placed over the ring.

• Mg wire stretched across electrode touching fuel sample.

• Lid of pot tightly screwed and pot filled with O2 to 25atm pressure.

• Bomb pot is placed in cu calorimeter with known mass of water

• Stirrer is worked and t1 is noted.

• Electrodes connected to 6V battery circuit complete which ignites Mg which in turn ignites the fuel sample

• Fuel sample burns and heat liberated • Heat liberated is absorbed by water in the calorimeter.

• Temp rises and maximum temperature noted (t2)
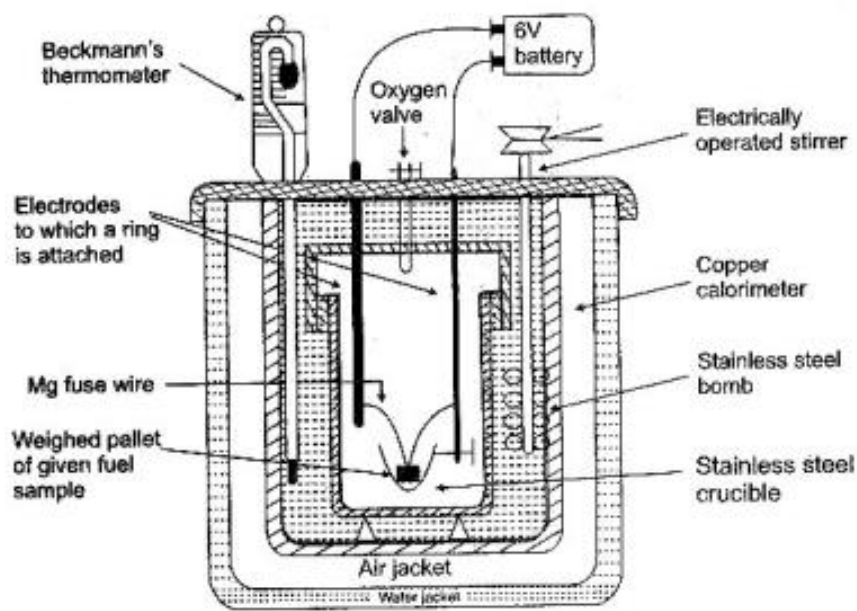
*Heat liberated by burning of fuel = Heat absorbed by water and calorimeter

Observations and Calculations

Mass of the fuel sample taken = m gm

Mass of water taken in the copper calorimeter = W gm

Water equivalent of calorimeter = w gm

Initial temperature of water = t_1 ^0C

Final temperature of water = t_2 ^0C

Specific heat of water = Cp = 1cal/g

Heat liberated by fuel = m* GCV

Heat absorbed by water and calorimeter = M * Cp * (t2-t1)

   Here, M=mass of water = W + w, Cp = 1cal/gm.

Now,

Heat liberated by burning of fuel = Heat absorbed by water and calorimeter

$$m * GCV = M * Cp * (t_2-t_1)$$

$$GCV = \frac{M * Cp * (t_2-t_1)}{m}$$ in Cal/gm or Kcal/gm

1cal = 4.187J

Simple GCV formula for Bomb Calorimeter

Corrections in simple GCV formula :

1)<u>Fuse Wire Correction (tf):</u> this is extra heat gained by the water Due to ignition of Mg wire which produce heat. So, tf is to be subtracted

 2)<u>Acid Correction (ta):</u> S and N of fuel at high temp. react with oxygen and hydrogen to form Sulphuric acid and nitric acid respectively

$S + H_2 + 2O2 \rightarrow H2SO4 + heat$ $N_2 + H_2 + 3O2 \rightarrow 2HNO3 + heat$

So ta is to subtracted from GCV

3)<u>Cooling correction (tc):</u> by the time maximum temperature is reached of water It begins to cool also and actual rise is lowered. Therefore tc i.e. cooling Correction is to be added.

Finally, $$GCV = \frac{(W + w)[(t_2-t_1) + tc] - (tf + ta)}{M}$$

Corrected GCV formula for Bomb calorimeter

TO BE USED ONLY WHEN QUESTION STATES CORRECTION

NUMERICAL EXAMPLES

Q. Calculate the Gross Calorific Value (GCV) in kJ/kg of 1 g of fuel containing 75% Carbon (C), when burnt in a Bomb calorimeter. The calorimeter contains 300 g of water and the water equivalent is 120 g. The temperature of water increased from 25.0°C to 27.3°C during the combustion.

Sol.

Given:

m = Mass of fuel = 1 g

t_1 = Initial temperature = 25·0°C

t_2 = Final temperature = 27·3°C

W = Mass of water = 300 g

w = Water equivalent of calorimeter = 120 g

Now,

GCV = $(W+ w) *(t2-t1)/m$ = (300+120) *(27·3−25·0)/1

GCV =966 kcal/kg x 4·187 = <u>4040·8 kJ/kg</u>

Q. 0.75 g of a fuel on complete combustion in a Bomb calorimeter increased the temperature of water from 23.5°C to 26.0°C. The calorimeter contains 450 g of water and the water equivalent of the calorimeter is 1000 g. The following corrections are:

- **Cooling correction = 0.03°C**

- **Fuse wire correction = 10 Cal**

- **Acid correction = 50 Cal**

  If the fuel contains 7% hydrogen, calculate the GCV and NCV.

Sol.

Given:

m = 0·75 g, W = 450 g, w = 1000 g, t_1 = 23·5°C, t_2 = 26·0°C

Cooling correction = 0·03°C

Fuse wire correction = 10 Cal

Acid correction = 50 Cal

%H = 7%

GCV = $(W + w)$ * $[(t2-t1) +tc) - (ta + tf) /m$

=450+1000) ×[(26·0−23·5)+0·03]−(50+10)/0·75

= 4824·67 Cal/g

also,

NCV = GCV −0·09 x %H x Latent heat

= 4824·67cal/g−0·09×7×587

=4455·16cal/gm

Determination of calorific value using Boy's Calorimeter

Principle

•A known volume of gaseous fuel sample is burnt in the combustion chamber of a Boy's calorimeter.

•The released heat is quantitatively absorbed by cooling water, circulated through copper coils surrounding the combustion chamber.

•The mass of cooling water and its rise in temperature are noted.

•The mass of water produced by condensation of steam is calculated.

•The calorific value of the fuel sample is then calculated from these data.
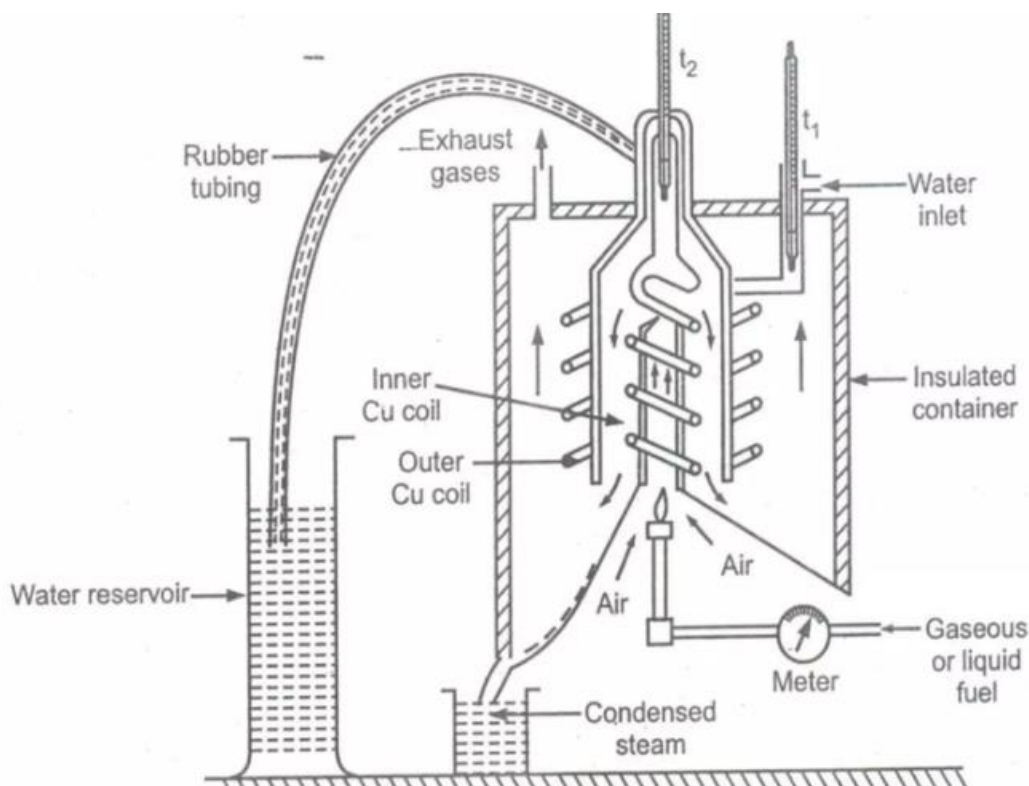
Working of Boy's Calorimeter

1.Warming up by circulation of water and burning gaseous fuel at constant rates for 15 minutes

2.The rates of fuel burning and water circulation controlled so that water leaves apparatus at atm pressure.

3. When steady conditions are met, following readings are taken:

a) The volume of gas burnt in time t

b) Quantity of water passed through coil in same time

c) Change in temperature (t2-t1)

d) Mass of water condensed in time t

Observations and Calculations

Volume of fuel burnt at STP in time, t = V m3

Mass of cooling water circulated in time, t = W kg

Steady temperature of incoming water = t_1^0C

Steady temperature of outgoing water= t_2^0 C

Rise in temperature = = (t2- t1) 0 C

Mass of water produced from steam condensation = m kg

Specific Heat of Water = Cp

Heat released by combustion of fuel = Heat absorbed by water

$$V \times GCV = W (t2- t1) \times Cp$$

$$GCV = \frac{W (t2- t1) \times Cp}{V}$$ in Kcal/m³   **1cal =4.187J**

GCV formula for Boy's Calorimeter

Latent heat of steam per m3 of fuel sample = $\frac{m \times 587 \text{ kcal}}{V}$

$$NCV = \frac{W(t_2-t_1) \times C_p}{V} - \frac{m \times 587}{V}$$

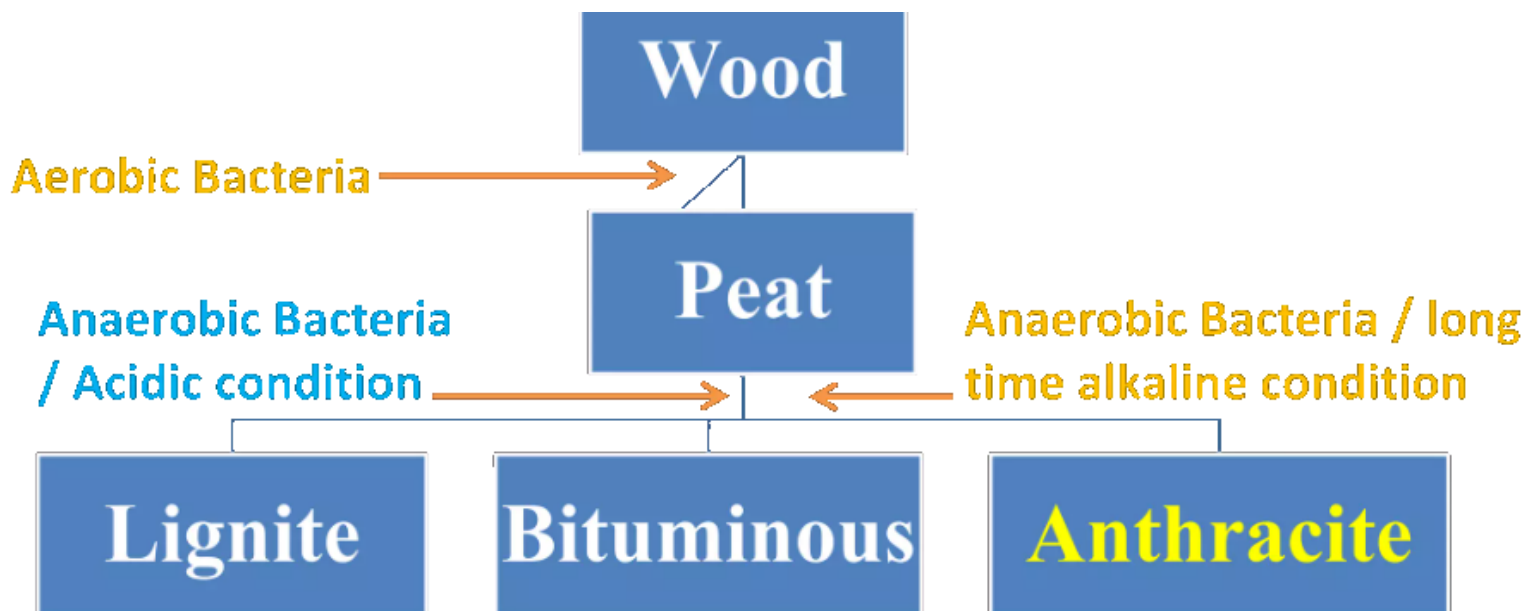**NCV formula for Boy's Calorimeter**

SOLID FUEL

Coal

Coal is a highly carbonaceous matter that has been formed as a result of alteration of vegetable matter (e.g., plants) under certain favorable conditions.

It mainly composed of C, H, N, and O, besides non-combustible inorganic matter

NOTE: COALIFICATION is the process of converting plants to coal under effect of pressure, temperature and bacteria.

Wood

Aerobic Bacteria ──────→

Peat

Anaerobic Bacteria / Acidic condition ──────→   ←────── Anaerobic Bacteria / long time alkaline condition

Lignite   Bituminous   Anthracite

Proximate Analysis

**

Percentage	Name of Instrument	Temperature	Duration	Formula
Moisture(M) %	Oven	110^0C	60 min	$m2 = \frac{m-m1}{m} *100$
Volatile Matter(Vm) %	Muffle Furnace	$950^0\pm25$	7 min	$Vm = \frac{m1 - m2}{m} * 100$
Ash content(Ash)%	Muffle Furnace	750^0C	30 min	$\frac{weight\ of\ residue}{m} * 100$
Fixed Carbon(FC) %	-	-	-	100-(M%+Vm%+Ash%+FC%)

Here, m = initial weight of coal.

1) **Moisture**: An air-dried coal sample is weighed in to a dry silica crucible and heated for about one hour at 100 C in an electric hot air-oven. The crucible is cooled first in air then in a desiccator and then weighed.
   - Moisture in coal evaporates during the burning of coal and it takes some of the liberated heat in the form of latent heat of evaporation.
   - Lesser the moisture content better is the quality of coal as a fuel.

2) **Volatile Matter**: The dried sample of coal left in the crucible in step 1 is then covered with a lid and placed in a muffle furnace, maintained at 950^0C. The crucible is taken out after 7 minutes of heating. It is cooled first in air then in a desiccator and finally weighed.
   - A high volatile matter containing coal burns with a long flame, high smoke and has low calorific value.
   - Lesser the volatile matter, better is the rank of coal

.

3) **Ash**: The residual coal left in the crucible in step (ii) is then heated without lid in a muffle furnace at 700-7500 C, until a constant weight of residue is obtained.

Ash-forming constituents in coal are undesirable for the following reasons:
• The calorific value of the coal is decreased.
• The removal and disposal of ash poses problems.
• The ash deposited in the fire bars interferes with circulation of air.
• If the ash fuses to form a clinker on the fire bars, it hinders air circulation and also promotes corrosion of the fire bars.

4) **Fixed carbon:** It is reported as the difference between 100 and the sum of the percentages of moisture, volatile matter and ash content of a coal sample.
• Higher the percentage of fixed carbon, greater is its calorific value and better is the quality of coal.
• Information regarding the percentage of fixed carbon helps in designing of the furnace and the fire-box.

Ultimate Analysis

1)Carbon and Hydrogen: A known mass of coal sample is burnt in excess of oxygen in combustion apparatus leading to formation of CO_2 and H_2O.

$$C + O_2 \rightarrow CO_2 \quad , \quad H_2 + 1/2O_2 \rightarrow H_2O$$

These are absorbed respectively in **KOH and CaCl2 tubes** of known weights. The difference in weight of KOH and $CaCl_2$ tube are equal to amount of CO_2 and H_2O respectively.

$CaCl_2 + 7\,H_2O \rightarrow CaCl_2 \cdot 7\,H_2O$ $2\,KOH + CO_2 \rightarrow K_2CO_3 + H_2O$
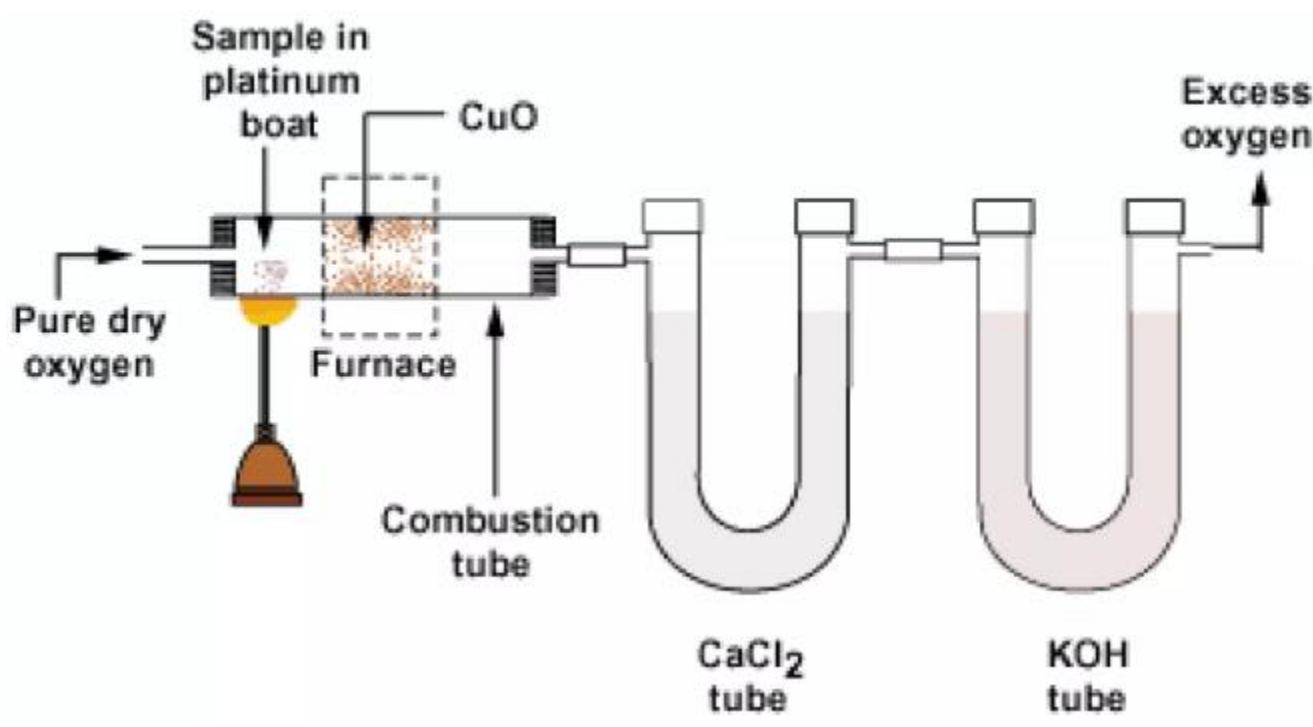
C%:

Let's say **'x'** is the weight increase of the KOH tube. This increase is the weight of the carbon dioxide (CO_2) formed

we know:

44 g of CO_2 contains 12 g of carbon (C).

So, if **'x' g of CO_2** is formed, the amount of carbon it contains will be:

$$= \frac{12 \ast x}{44} \text{ gm}$$

if the weight of the coal sample is **W gm**, the percentage of carbon in the coal is

$$\%Carbon(C) = \frac{12 \ast x \ast 100}{44 \ast W}$$

H% :

Let's say **'y'** is the weight increase of the $CaCl_2$ tube. This increase represents the weight of the water (H_2O) formed.

we know:

18 g of H_2O contains 2 g of hydrogen (H)

So, if **'b' g of H_2O** is formed, the amount of hydrogen it contains will be:

$$= \frac{y*2}{18}$$

if the weight of the coal sample is **W grams**, the percentage of hydrogen in the coal is:

$$\% \text{ Hydrogen(H)} = \frac{2*y*100}{18*W}$$

NOTE:

For a coal to be of good quality its %C and %H should be high, as its calorific value will be high.

2)Nitrogen: Its estimation is done using Kjeldhal's method. The method is as following:

- Take 1g of powdered, air-dried coal in a Kjeldahl flask. Add **concentrated H_2SO_4** and **$HgSO_4$**, with **K_2SO_4** as a catalyst. Heat it until the solution becomes clear, converting all nitrogen to **$(NH_4)_2SO_4$**.
- After cooling, add excess **NaOH**, which releases **NH_3**.
- The released **NH_3** is absorbed in a measured amount of standard acid solution. Any unused acid is then titrated with **NaOH**.

- To calculate how much acid reacted with NH_3, do a blank titration with the same acid (without NH_3 passing through).
- The difference between the back titration and blank titration tells you the amount of acid used by the NH_3.
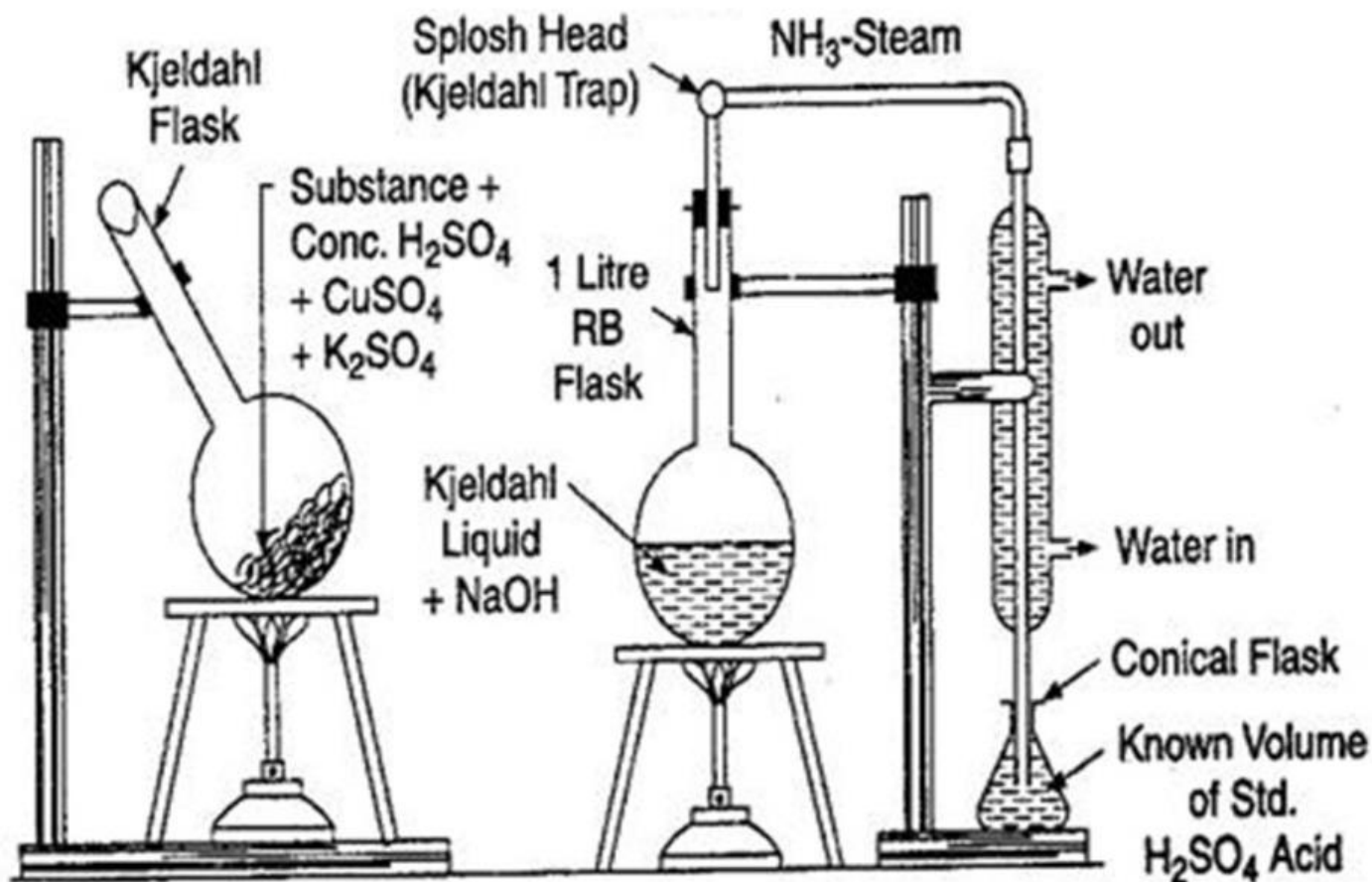
If **X** normal HCl is used as std. acid and **X** normal NaOH for blank AND back titration

V_1 = back titration result, V_2 = blank titration result

So, V_2- V_1 = volume of acid consumed by NH_3

1000ml 1 N HCl = 1N NH_3 = 14 g of N

Therefore V_2- V_1 ml of 'X' HCl = $\dfrac{(V_2- V_1)* X * 14}{1000}$ gm of Nitrogen

Therefore, $\%N = \dfrac{(V_2 - V_1) * X * 14 * 100}{1000 * W}$

Here, W= weight of sample of coal taken

NOTE:

Nitrogen doesn't contribute to the calorific value of coal; hence a good quality coal should have as little as no nitrogen in it.

3)Sulphur: **Its percentage is determined using Eschka's method, which is as following:**

- Burn a measured amount of coal completely in a bomb calorimeter.
- Sulfur in the coal is converted to SO_2 and SO_3 during combustion.
- Collect the ash left after burning and extract it with diluted HCl.
- Add **barium chloride** to the acid extract to form **barium sulfate ($BaSO_4$)** as a precipitate.
- Filter, wash, ignite, and weigh the barium sulfate to measure the sulfur content.

Let '**a**' the mass of $BaSO_4$ ppt,

1 M **$BaSO_4$** = 1M Sulphur

Therefore,

233 g of **$BaSO_4$** = 32 g of S

a gm of $BaSO_4$ = $\dfrac{a * 32}{233}$

hence,

$\%S = \dfrac{a * 32 * 100}{233 * W}$

W= weight of sample of coal.

NOTE:

(v) **Oxygen**:

$$\% \text{ Oxygen} = 100 - \% (C + H + N + S)$$

NOTE:

LIQUID FUEL

Petroleum (Crude oil)

- Petroleum has been formed millions of years ago by anaerobic decay of marine plant and animal life under the influence of high temperature and pressure.

- It's a complex mix of hydrocarbons (paraffins, cycloparaffins, olefins, and aromatics) with small amounts of organic compounds containing N, O, and S, plus trace inorganic compounds.

- The average composition of crude oil is: C: 83 - 87%; H: 11 - 15 %; S: 0 – 3%, N and O: 0.1- 5%.

Classification of Petroleum

Paraffin based

Contains saturated hydrocarbons from CH_4 till $C_{35}H_{72}$ little of naphthalene and aromatics.

Asphaltic based

It contains mainly cycloparaffins (naphthalene) with little of paraffin and aromatics.

Mixed type

contains both paraffinic and asphaltic hydrocarbons.
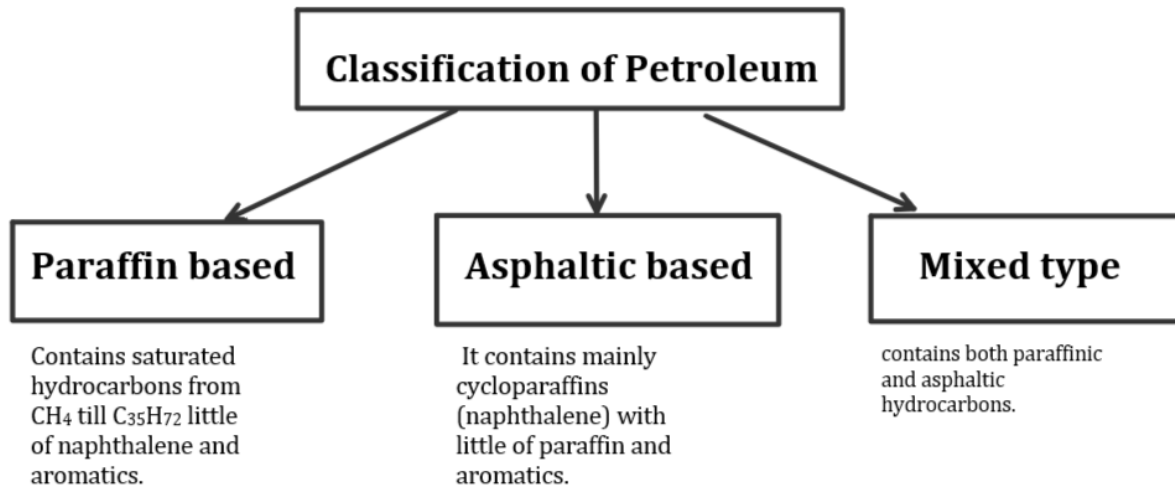
Mining of petroleum

1. Petroleum is mined by drilling holes into the Earth's crust.

2. Pipes are inserted deep into oil-bearing rocks.

3. Compressed air is forced in, making the oil gush out.

4. The extracted oil is transported to refineries through pipelines.

Cap rock

Gas

Oil

Water

Impervious rock
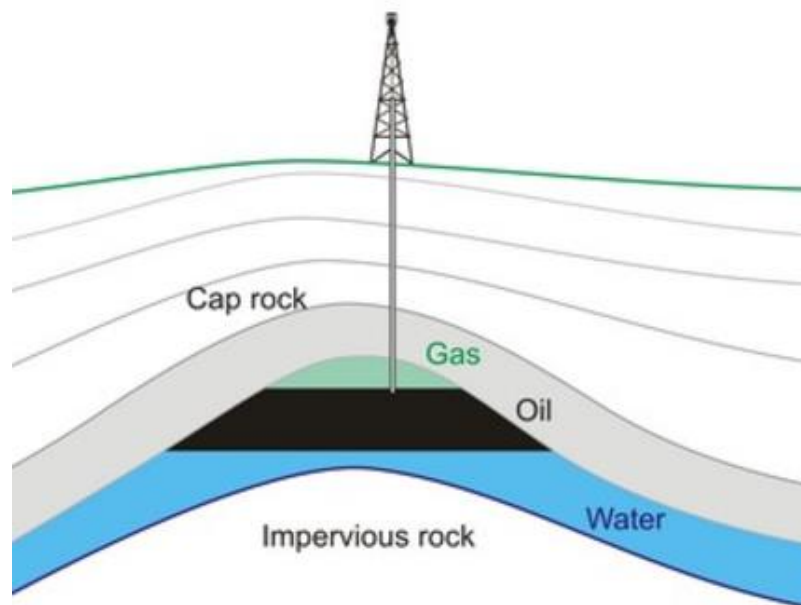
Petroleum refining :

Petroleum refining is a process that involves separating crude oil into useful products such as petrol, diesel, and kerosene by heating it and separating components based on their boiling points. This is done within a refinery using a distillation tower.

The refining process is done in three steps:

1. **Separation of water:** Oil and water emulsions are separated by passing them through highly charged electrodes. The water particles join together to form a separate layer, making it easy to remove. This process is called Cottrell's process.
2. **Removal of Harmful sulfur compounds:** Treatment of oil CuO leads to formation of CuS ppt which is further removed by filtration.
3. **Fractional distillation:**
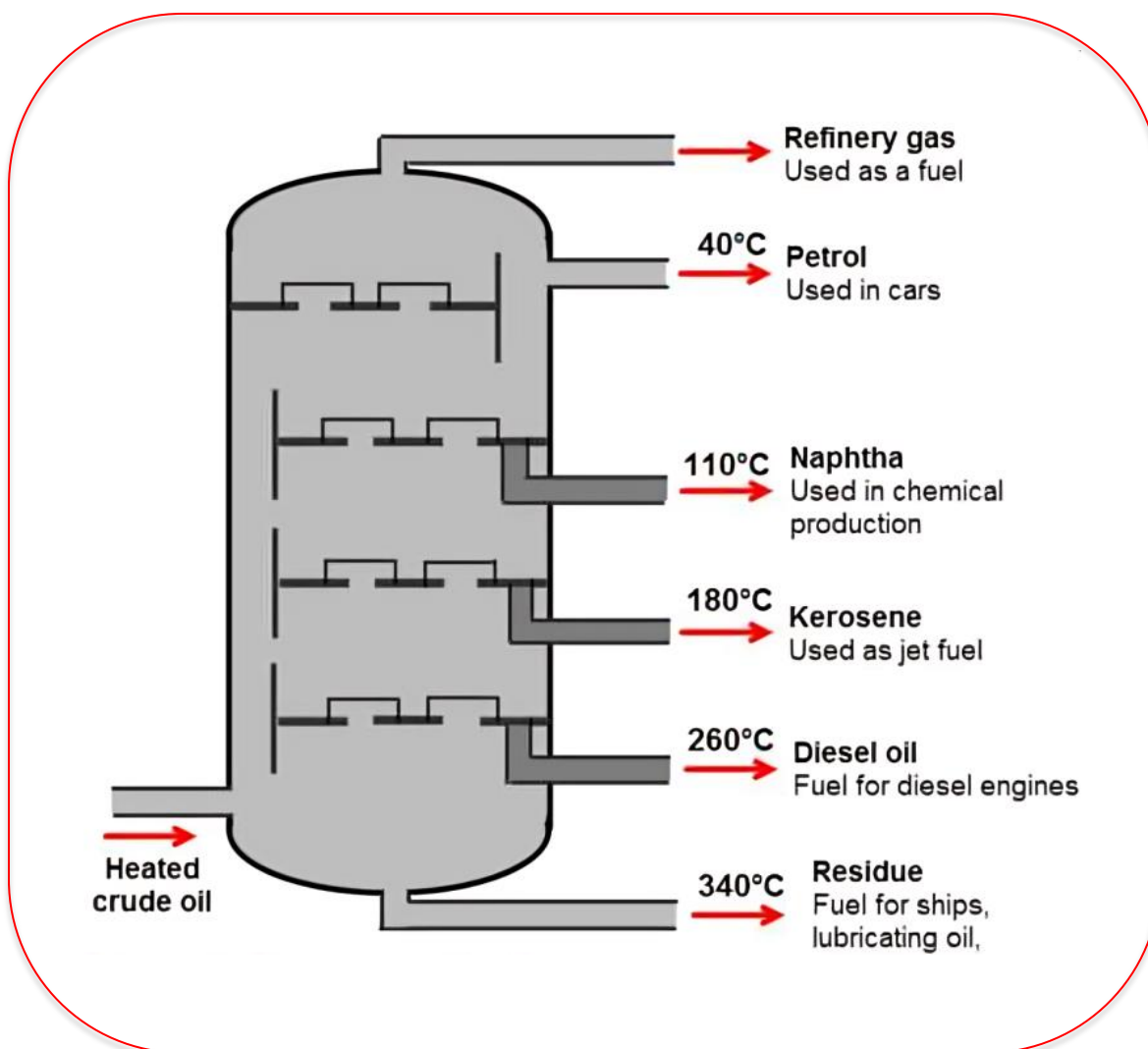
A] Crude oil is first cleaned of water and sulfur, then heated to **350-400°C** before being fed into a fractionating column.

- **How Fractionation Works:** The heated vapours rise up through the bubble-cap fractionating column.
    Lighter, more volatile components condense at the top, while heavier, less volatile ones settle at the bottom.
- **C1-C4 (Refinery gases)**: Used as **bottled gas**, ideal for heating and cooking due to its low boiling point and high volatility. (boiling range: **<30°C**)
- **C5-C9 (Gasoline/Petrol)**: This fraction becomes **car fuel** (boiling range: **30-70°C**).
- **C9-C10 (Naphtha)**: Used mainly for **chemical production** (boiling range: **120-180°C**).
- **C10-C16 (Kerosene)**: A crucial fuel for **aircraft** (boiling range: **180-250°C**).
- **C16-C18 (Diesel oil)**: Powers **cars, trucks, and buses** (boiling range: **250-320°C**).
- **C30-C70 (Fuel oil)**: Used in **ships and power stations** for heavy-duty energy needs (boiling range: **320-400°C**).
- **>C70 (Residue)**: Forms **bitumen**, which is used for building roads and roofing (boiling point above **400°C**).

Before learning about power alcohol and Bio diesel, we need to get idea of two terms Octane Number of petrol and Cetane Number for diesel

Octane Number:

- Knocking: **A petrol engine** produces cracking noise & vibration together called as Knocking.

- The knocking character of a petrol is expressed as "Octane number".

- is determined by comparing the fuel's performance to a mixture of iso-octane (which resists knocking) and n-heptane (which knocks easily). A **higher octane number means better resistance to knocking.**

- for reference, motor cycles and cars require at least 85 O.N fuel while airplane and helicopter require above 100 O.N fuel.

Cetane Number of Diesel:

- The intense vibration, rattling metal sounds made by a **diesel engine** due to time lag or delay in ignition of diesel is known as knocking.
- The cetane number of **diesel** is the percentage of n-hexadecane ($C_{16}H_{34}$) in a blend of n-hexadecane and 2-methyl naphthalene ($C_{11}H_{10}$) that matches the ignition behaviour of the diesel being tested. It indicates how easily the diesel ignites in an engine.

Power Alcohol

Power alcohol is a homogenous mixture of 20-25% Ethyl Alcohol and rest of its petrol.

Manufacture of Power alcohol: Ethyl alcohol is obtained from molasses. Sucrose in molasses is converted to glucose and fructose by yeast

$$Sucrose + H_2O \longrightarrow 2C_6H_{12}O_6 \text{ (glucose + fructose)}$$

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$$
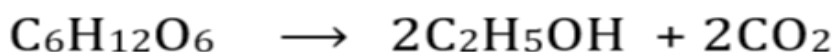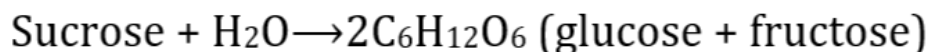
**This fermented liquid having 18-20% alcohol is fractional distilled to give Rectified spirit (90-95%) and treated with lime and distilled to get absolute alcohol.

**Advantages:

1. Better octane no. (90) as compared to petrol (60-70).
 2. Alcohol burns clean hence reduces emission of harmful gases.
 3. It absorbs moisture so keep petrol free of moisture.
 4. Deposition of gummy products on internal parts of engine is reduced
 5. It reduces overheating of engine thereby extending engine life.
 6. Ethanol is renewable source of energy hence dependence on other countries
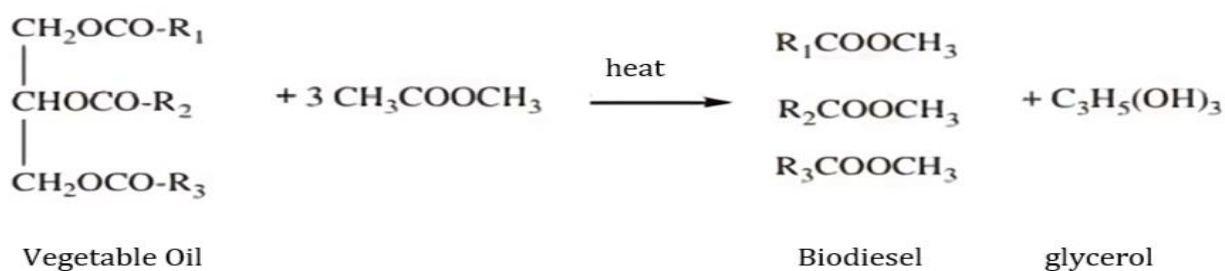 is reduced.

** Disadvantages:

1. Reduces calorific value of petrol.
 2. Causes starting trouble sine has high surface tension and difficult to vaporise.
 3. Gets converted to acetic acid easily causing corrosion of engine parts.
 4. Modification of air inlet or choke required as requires less air for combustion.

Bio-diesel:

Biodiesel is biofuel obtained from renewable sources of energy such as Vegetable oils or animal oils by trans-esterification.

(Trans-esterification is a process of converting one ester into another ester.)

$$
\begin{array}{c}
\text{CH}_2\text{OCO-R}_1 \\
| \\
\text{CHOCO-R}_2 \quad + \ 3\ \text{CH}_3\text{COOCH}_3 \quad \xrightarrow{\text{heat}} \\
| \\
\text{CH}_2\text{OCO-R}_3
\end{array}
\quad
\begin{array}{c}
\text{R}_1\text{COOCH}_3 \\
\text{R}_2\text{COOCH}_3 \quad + \ \text{C}_3\text{H}_5(\text{OH})_3 \\
\text{R}_3\text{COOCH}_3
\end{array}
$$

Vegetable Oil   Biodiesel   glycerol

Here, R can be any carbon chain for example methyl palmitate ($CH_3(CH_2)_{14}$), methyl stearate ($CH_3(CH_2)_{16}$) etc.

Steps for preparation:

1.Cheap, non-edible vegetable or animal oil heated to 110C to remove moisture.

2.About 2% NaOMe and 20% methanol added to reactor.

3.The mixture refluxed at 60-70C for 1-7 hrs.

4.Mixture cooled and mixed with water to dissolve glycerin.

5.Water insoluble biodiesel phase is separated from water.

6.Further processed by adding antioxidants to avoid oxidation.

**Advantages:

1. A renewable, eco-friendly energy source that is readily available locally
2. Non-toxic and free from sulfur, making it environmentally safe.
3. Burns cleanly with oxygen, has a high flash point, and is safe to handle.
4. Offers better lubricating properties, a higher cetane number than conventional oils, and serves as an effective solvent.

** Disadvantages:

1. Higher cloud and pour points than conventional diesel (cloud point: temperature where wax crystals form, pour point: lowest temperature fluid flows).
2. Incompatible with rubber hoses and gaskets.
3. Not suitable for certain metals and plastics.

GASEOUS FUEL

HYDROGEN GAS

Hydrogen gas is currently considered as a future fuel, for various reasons because theoretically it has numerous advantages as fuel but its practical use is far from reality as of now, but scientists and engineers are working on it to be used as a replacement of petroleum and diesel.

PRODUCTION:

A) Steam Reforming of Methane (CH4)

*   Methane (CH_4) from natural gas (NG) is mixed with steam.
*   Passed over a nickel (Ni) catalyst at 700–1000°C
*   This produces water gas (CO + H2O):

$$CH_4 + H_2O \xrightarrow{\text{Ni}} CO + 3H_2$$
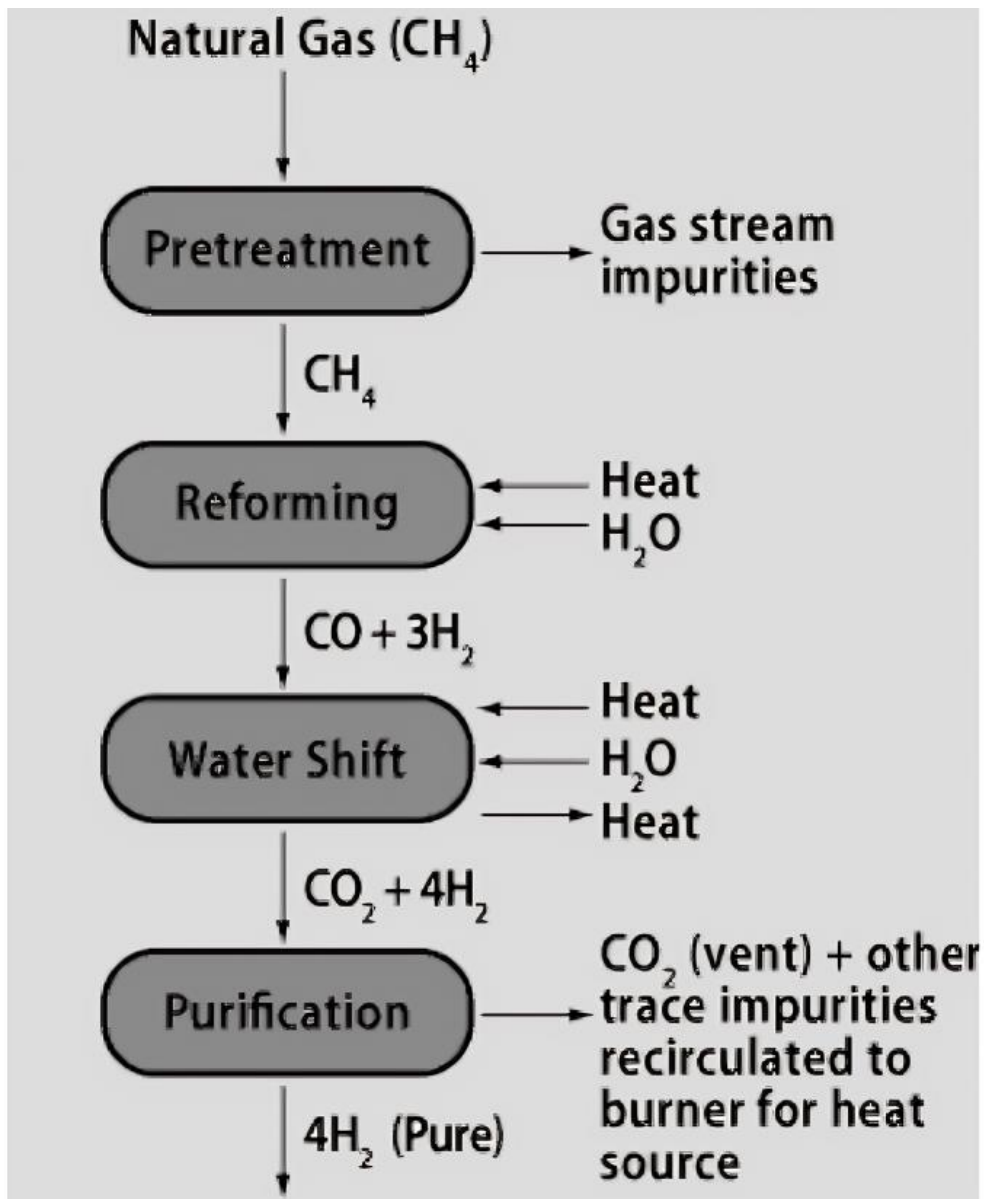$$\text{(Water gas)}$$
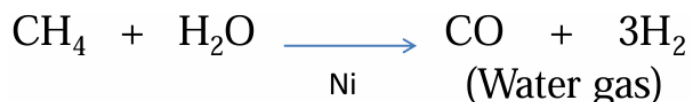
Water Gas Shift Reaction:

- Gas from the steam reformer is mixed with additional steam.

- Cooled to 400°C and passed through a shift converter containing Fe-Cu catalyst.

- This finally produces H2 and CO2

$$CO + H_2O \longrightarrow CO_2 + H_2$$
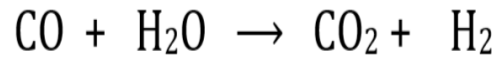
The CO2 must be removed this is done through following methods:
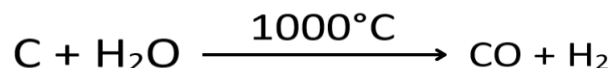
1. By dissolving CO_2 in water under high pressure.
2. By reacting with potassium carbonate (K_2CO_3).
3. By using an aqueous solution of amines.
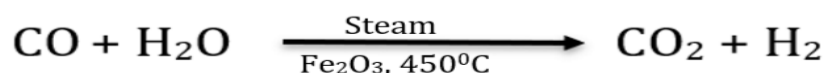
B) Steam reforming of Coke

This is an affordable method involving coke and water as raw material.

- A current of steam is passed over red-hot coke.

$$C + H_2O \xrightarrow{1000°C} CO + H_2$$

Water Gas Shift Reaction:

The Gaseous mixture thus formed is mixed with steam, cooled to 400^0C and passed over Fe_2O_3 in shift converter.

$$CO + H_2O \xrightarrow[Fe_2O_3,\ 450^0C]{Steam} CO_2 + H_2$$
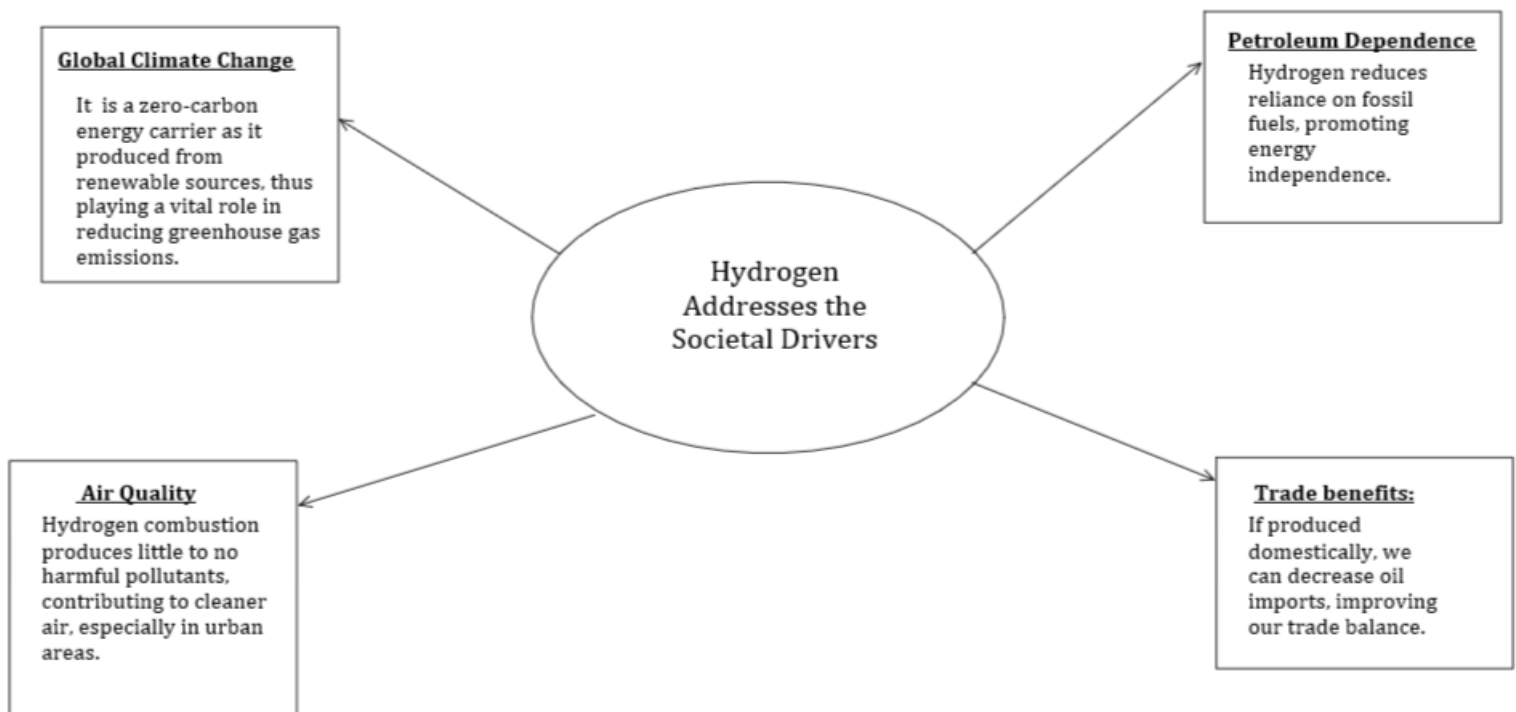
PROMISES IN HYRDOGEN

- **Clean Energy Source**: produces only water vapor when burned or used in fuel cells.
- **Abundant Availability**: Hydrogen is the most abundant element in the universe, available from water, biomass, and natural gas.
- **Renewable Potential**: Can be produced from renewable sources like solar, wind, or water electrolysis
- **Supports Energy Transition**: Plays a critical role in decarbonizing industries, transport, and power sectors.
- **Reduced Air Pollution**: No particulate matter, sulfur oxides, or nitrogen oxides emissions when used.
- Roadblock to hydrogen economy is effective and safe hydrogen storage.

CHALLENGES TO HYDROGEN MOBILITY

1. Development of lightweight, compact, durable, and cost-effective fuel cell propulsion systems.
2. Set up of efficient hydrogen production and distribution system.
3. Invention of portable hydrogen storage systems that are lightweight, compact, durable, affordable, and satisfices the vehicle's needs.

Global Climate Change

It is a zero-carbon energy carrier as it produced from renewable sources, thus playing a vital role in reducing greenhouse gas emissions.

Petroleum Dependence

Hydrogen reduces reliance on fossil fuels, promoting energy independence.

Hydrogen Addresses the Societal Drivers

Air Quality

Hydrogen combustion produces little to no harmful pollutants, contributing to cleaner air, especially in urban areas.

Trade benefits:

If produced domestically, we can decrease oil imports, improving our trade balance.

STORAGE OF HYDROGEN:

Storage of hydrogen is most crucial of it being used as fuel. It can be stored using 2 different types of methods:

1) <u>Physical Storage</u>:
   a) By compressing hydrogen at low temperature (Liquification).
   b) By its adsorption on porous Carbon materials

   Cryogenic H-tanks are light and more volume of H_2 can be stored by liquification, however energy loss due to cooling and

liquification and insulation to prevent increase in temperature makes it difficult to adapt.

2) Chemical Storage:

In form of metal hydride, it is safe and efficient method to store H_2.

Metal/its alloy + H_2 → M-H

It enables hydrogen storage and release at low temperatures and pressures, making it portable. However, this method is too costly for the given efficiency.

PROBLEMS:

1) Hydrogen has the highest chemical energy density (142 MJ/kg) but suffers from poor volumetric density
2) Storage methods include compressed gas, liquid hydrogen, and metal hydrides (e.g., Mg_2NiH_4, $LaNi_5H_6$).
3) DOE targets: 6.0 wt.% with efficient binding energy by 2010, increasing to 9.0 wt.% by 2015.
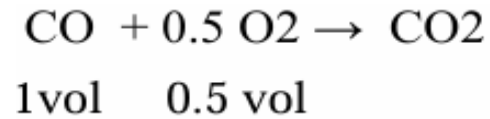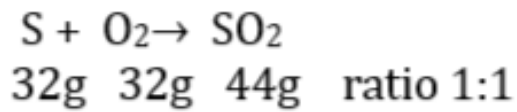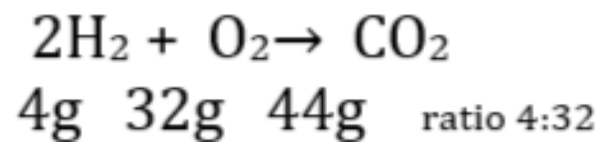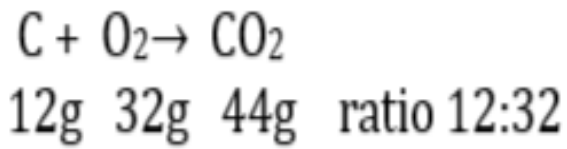
AREA TO FOCUS:

1) Improve gravimetric/volumetric density
2) Reduce production and storage costs
3) Improve safety for widespread hydrogen storage adoption.

COMBUSTION REACTIONS

In combustion reactions substances react with oxygen and heat resulting energy release in form of light and heat.

NOTE:

- Complete combustion of carbon compounds forms CO_2
- Combustion of hydrogen leads to formation of H_2O

$$C + O_2 \rightarrow CO_2$$
12g 32g 44g ratio 12:32

$$2H_2 + O_2 \rightarrow CO_2$$
4g 32g 44g ratio 4:32

$$S + O_2 \rightarrow SO_2$$
32g 32g 44g ratio 1:1

$$CO + 0.5\ O2 \rightarrow CO2$$
1vol   0.5 vol

- At STP (t = 273K, P = 1atm)
  - 22.4 lit any gas = 1 mole of that gas
  - 22.4 lit of oxygen = 1 mole oxygen = 32g
- Nitrogen and ash present in the fuel, they are non-combustible
- Total theoretical O_2 for fuel = sum of O_2 required for individual components of fuel.
- Final O_2 required = Theoretical O_2 required – Internal O_2
- Air contains 21% O_2 by volume and 23% O_2 by weight.
- Quantity of Air (In kg) = O_2 req. (in Kg) x 100 / 2
- Volume of Air (in m³) = O_2 req (in m3) x 100 / 21
- Qty of air actually supplied = theoretical qty of air *{100+%excess air/ 100}