

## UNIT - IV FUELS

End-Sem Exam = 17 Marks

### \* Question Paper Pattern -

- Ques. 3 (a) — 4 M (Numerical)  
 (b) — 3 M } (Theory)  
 (c) — 5 M }  
 (d) — 5 M }

OR

- Ques. 4 (a) — 4 M (Numerical)  
 (b) — 3 M } (Theory)  
 (c) — 5 M }  
 (d) — 5 M }

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- Numerical on - GCV & NCV of Bomb & Boy's Calorimeters, Proximate & Ultimate analysis of coal.

### \* Reference books for Unit - IV :-

- Engg. Thermodynamics - R.K. Rajput
- Engg. Chem. - Shashi Chawla
- " - O.G. Palana

### \* Course Objectives :-

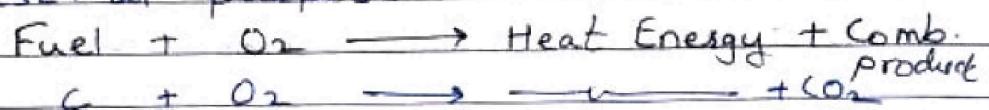
To study conventional & alternative fuels with respect to their properties & applications.

## \* Index / Mind Map of Unit - IV :-

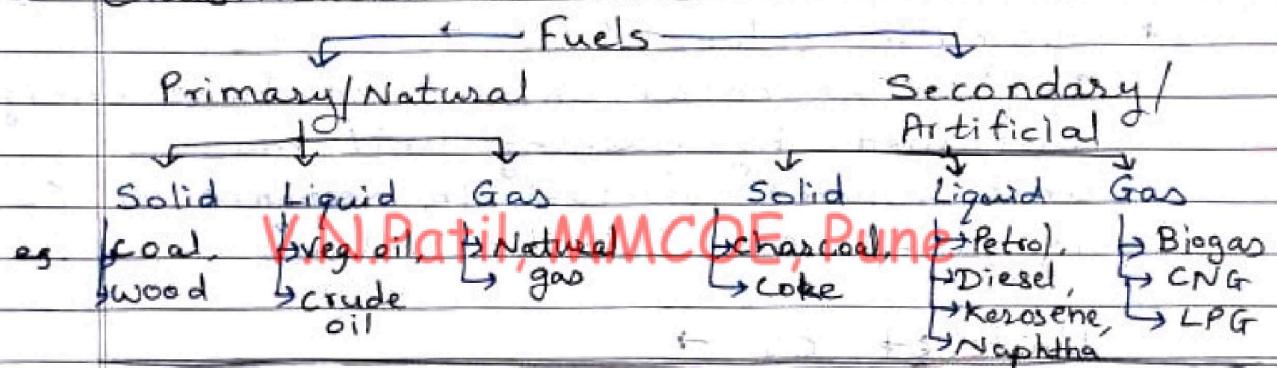
- Pre-requisit of Fuel - Uses, Examples, Fuel cells, Function, Conventional & Non-conventional fuels...
- Introduction
  - Def<sup>n</sup> of fuel, Characteristics, Classif<sup>n</sup>,
- Calorific Value - Def<sup>n</sup>, Units
  - Types of CV, Rel<sup>n</sup> bet<sup>n</sup> GCV & NCV,
  - Units of CV.
- Determination of CV
  - Bomb & Bunsen Calorimeter -  
(Principle, Diag, Construct, Working, Calculations)  
Numericals)
  -
- Solid Fuels - Coal, Analysis (Proximate, Ultimate), Numericals.
- Liquid Fuels - Petroleum / Crude oil - Refining, Fractional Distill<sup>n</sup>, Diag, Process fractions
- Gaseous Fuels - CNG - Composition, Prep, Application
  - Hydrogen Gas - Future fuel, Production, Storage & Transporta<sup>n</sup> difficulty.
- Power Alcohol } Def<sup>n</sup>, Process, Re<sup>n</sup>, Merits
- Biodiesel } + Demerits

Fuel :-

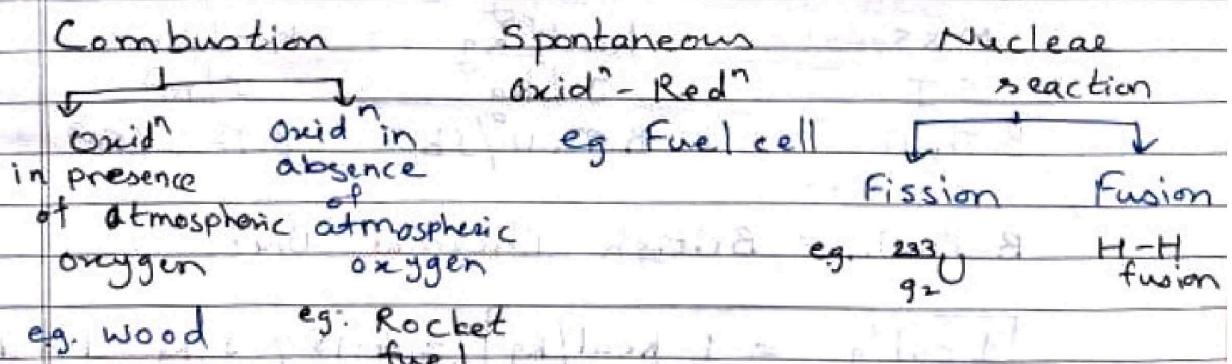
Def<sup>n</sup> - It is combustible matter which burns in presence of O<sub>2</sub> to give large amount of heat energy which is utilized economically for domestic & industrial purpose.



Classification of Fuels :-



Fuels (on the basis of chemical reactions)



Final Test - 1

Characteristics of Good fuel :-

- 1) High calorific value
- 2) Low % ash content
- 3) Low volatile matter
- 4) Moderate velocity of combustion
- 5) Harmless combustion products
- 6) Moderate ignition temperature
- 7) Low cost
- 8) Easy storage & transportation

\* Calorific Value - (CV) →

Def' - The total amount of heat energy obtained by burning unit mass or unit volume of fuel in presence of  $O_2$  is called **V.N.Patil, MAMCOE, Pune**

Units of CV →

	Solid/Liquid fuel	Gaseous fuel
C.G.S	cal/g	cal/lit
M.K.S	kcal/kg	kcal/m <sup>3</sup>
S.I	J/kg	J/m <sup>3</sup>
B.Th.U.	B.Th.U./lb	B.Th.U./ft <sup>3</sup>

B.Th.U. = British Thermal Unit

$$1 \text{ cal/g} = 1 \text{ kcal/kg} = 4.187 \text{ J/kg} = 1.055 \text{ B.Th.U./lb}$$

$$1 \text{ cal/lit} = 1 \text{ kcal/m}^3$$

Types of CV :-

$\downarrow$   
GCV / HCV

Gross / Higher  
Calorific value

$\downarrow$   
NCV / LCV

Net / Lower  
calorific value

GCV / HCV :- Gross / Higher Calorific Value -

Total amount of heat energy obtained by burning unit mass / vol<sup>m</sup> of fuel in presence of O<sub>2</sub> & the combustion products are allowed to cool at room temp. i.e. 15°C.

NCV / LCV :- Net / Lower Calorific Value -

Total amount of heat energy obtained by burning unit mass / vol<sup>m</sup> of fuel in presence of O<sub>2</sub>. **V.N.Ratil, MMCOE, Pune** the combustion products are allowed to escape.

Relation bet" GCV & NCV :-

$$\text{GCV} > \text{NCV}$$

$$\boxed{\text{NCV} = \text{GCV} - \frac{9H}{100} \times \text{Latent heat of steam}}$$

or

$$\boxed{\text{NCV} = \text{GCV} - 0.09H \times \text{Latent heat of steam}}$$

where H = % of hydrogen in fuel

$$\begin{aligned} \text{Latent heat of steam} &= 587 \text{ cal/g} \\ &= 587 \text{ kcal/kg} \end{aligned}$$

\* Determination of, CV :→

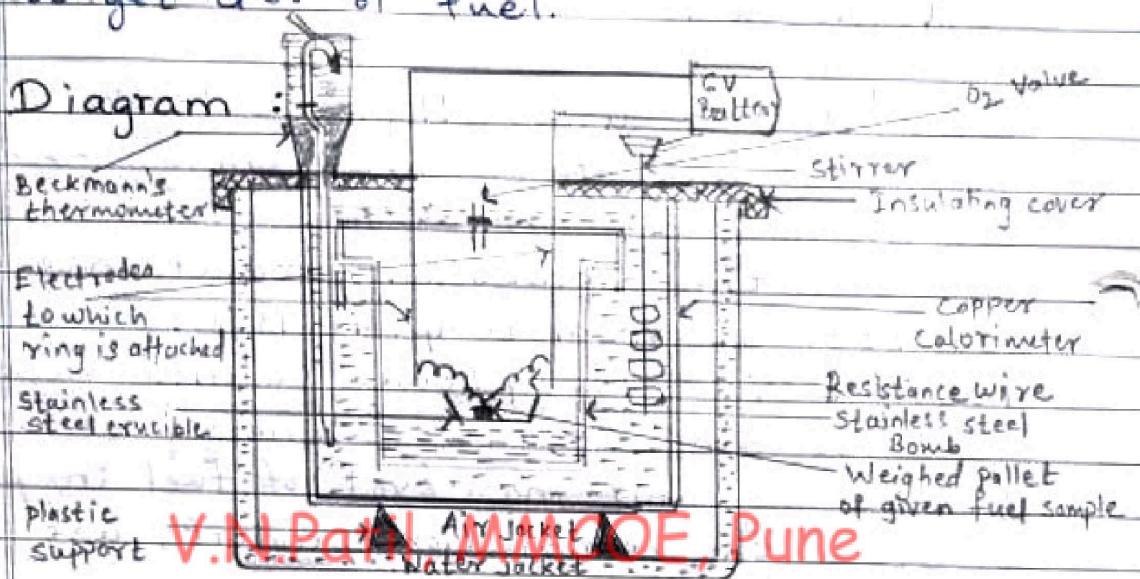
$\downarrow$   
Bomb Calorimeter

$\downarrow$   
Boy's Calorimeter

### Bomb Calorimeter :-

Principle - It is used to determine CV of solid as well as liquid fuels, using bomb pot, where combustion products are cooled to get GCV of fuel.

Diagram :-



**Construction** - Bomb calorimeter consists of -

- i) Stainless steel Bomb containing ring for crucible with two electrodes & one inlet for O<sub>2</sub> valve.

- ii) Bomb pot is kept in a Cu calorimeter containing water & electrically operated stirrer for uniform heating with Beckmann's thermometer which measures  $\frac{1}{100}$ th or 0.01 part of a degree ( $1^\circ$ )

- iii) Calorimeter is surrounded with air jacket & water jacket to avoid heat loss due to radiation.

## Working. -

- i)  $x$  g of water is taken in Cu calorimeter with  $t_1$  °C temp recorded.
  - ii)  $x$  g fuel sample is placed in crucible in which fine Mg wire inserted which is tied to electrodes.
  - iii) When battery 6V is operated with constant vol<sup>m</sup> of 25 atmospheric oxygen, fuel starts burning because of Mg wire.
  - iv) Heat generated during this process is absorbed by water & bomb apparatus, whose temp. is recorded as  $t_2$  °C.
  - v) Thus, GCV of given fuel sample can be calculated.

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## Calculations :-

$$\text{Heat produced by fuel} = \text{Heat absorbed by water}$$

$$\therefore \text{GCV} = \frac{(tw + w)(t_2 - t_1)}{x}$$

cal/g or  
kcal/kg

### Corrections :-

$$GCV = \frac{(W+w)(t_2-t_1+t_c)}{m} - (a+f) \quad \text{at/g or}$$

$$NCV = GCV - 0.0941 \times \text{latent heat of steam} \quad \frac{\text{cal/g of}}{\text{kcal/kg}}$$

where  $\rightarrow x = \text{wt of fuel}$ ,  $H = \text{g. Hydrogen in fuel}$ ,  
 $t_1 = \text{initial temp of water}$ ,  $t_2 = \text{final temp. of H}_2\text{C}$   
 $W = \text{wt of water}$  i.e. initial

$w$  = wt of water in calorimeter

w = water equivalent of calorimeter

$a$  = acid correction

$f = \text{fuse wire correction}$  (or cooling correction)

### Numerical on Bomb Calorimeter -

Ques. Complete combustion of 1.050 gm of fuel was carried out in a calorimeter in presence of excess of oxygen. The temperature of 1500 gm of water of calorimeter raised from 25.7 to 27°C. If the water equivalent of calorimeter is 125 gm & % Hydrogen is 3.5%, calculate the calorific value of the fuel.

$$\rightarrow \text{Given} - x = 1.050 \text{ gm}$$

$$t_1 = 25.7^\circ\text{C}$$

$$t_2 = 27^\circ\text{C}$$

$$W = 1500 \text{ gm}$$

$$w = 125 \text{ gm}$$

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$$\begin{aligned} \therefore GCV &= \frac{(W+w)(t_2-t_1)}{x} \\ &= \frac{(1500+125)(27-25.7)}{1.050} \\ &= \underline{\underline{2011.90 \text{ cal/gm}}} \end{aligned}$$

$$\begin{aligned} NCV &= GCV - 0.09 H \times \text{Latent heat of steam} \\ &= 2011.90 - 0.09(3.5) \times 587 \\ &= \underline{\underline{1827 \text{ cal/gm}}} \end{aligned}$$

iii) Condensed steam

Ques. The determination of calorific value of a coal gave following data -

Weight of coal sample = 0.9 gm

Water equivalent of calorimeter = 440 g

Weight of water = 2500 g

Rise in temp. = 2.4 °C

Cooling correction = 0.052 °C

Fuse wire = 10 cal.

Acid correction = 12 cal.

Calculate Gross & Net calorific value, if the coal contains 8% hydrogen. Assume latent heat of steam equal to 600 cal/gm.

→ Given -  $w = 2500 \text{ g}$

$w = 440 \text{ g}, w = 0.9 \text{ g}, (t_2 - t_1) = 2.4^\circ\text{C}$ ,

$t_c = 0.052^\circ\text{C}$ ,  $f = 10$ ,  $a = 12$ ,  $\%H = 8$ ,

Latent heat of steam = 600 cal/g

$$GCV = \frac{(w + w)(t_2 - t_1 + t_c) - a - f}{w}$$

$$= \frac{(2500 + 440)(2.4 + 0.052) - 12 - 10}{0.9}$$

$$= 7186.88 \text{ cal/gm}$$

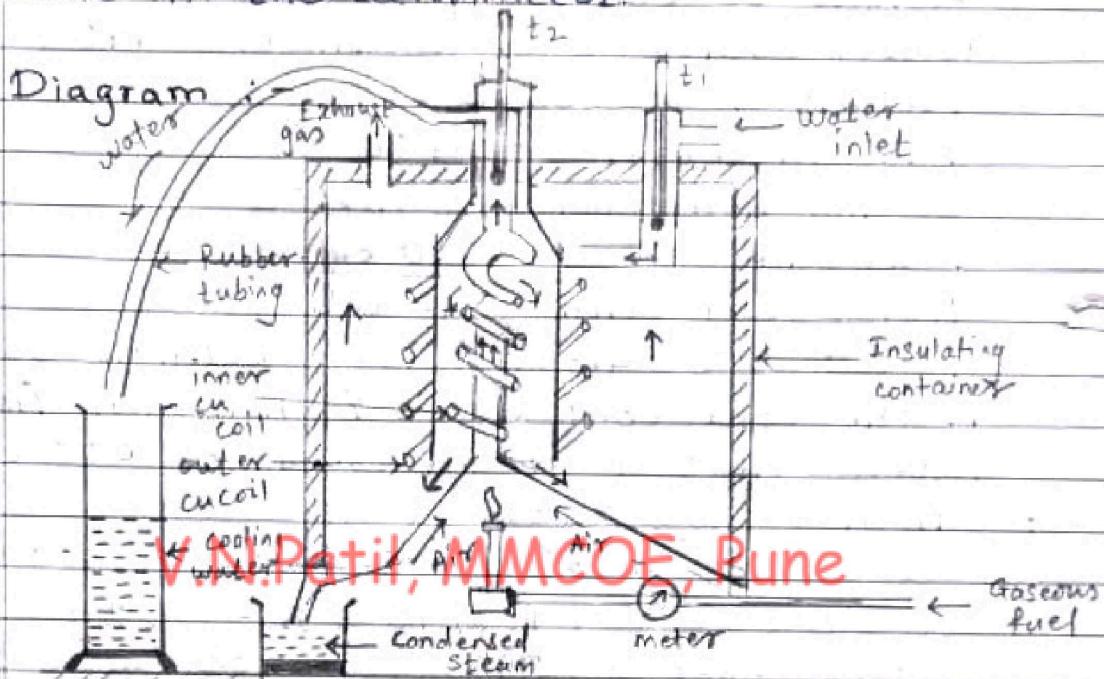
$$NCV = GCV - 0.09 H \times \text{Latent heat of steam}$$

$$= 7186.88 - [(0.09 \times 8) \times 600]$$

$$= 6754.88 \text{ cal/gm}$$

## 2) Boy's Calorimeter :-

Principle - It is used to determine, CV of gaseous fuel by burning gaseous fuel at const. rate in the calorimeter.



Construction - i) Gas burner - to burn the gaseous fuel at a known pressure.

ii) Combustion chamber/chimney - contains inner & outer Cu coil through which water flows.

iii) Inlet & outlet thermometers - to measure temp. of inlet & outlet water.

iv) Insulating cover & container for steam

Working :-

i)  $V \text{ m}^3$  of gaseous fuel is burnt.

ii)  $W \text{ kg}$  water with  $t_1^\circ\text{C}$  temp is allowed to pass through chimney.

iii) As soon as fuel is burnt, Cu coils are heated & heat energy is absorbed by water flowing through it, whose temp. is recorded as  $t_2^\circ\text{C}$ .

- iv) Condensed steam is collected during the combustion of fuel.
- v) Thus, GCV & NCV can be calculated.

### Calculations -

$$\text{Heat produced} = \text{Heat absorbed}$$

$$\text{by fuel} \qquad \qquad \qquad \text{by water}$$

$$\therefore \text{GCV} \times L = W(t_2 - t_1)$$

$$\therefore \text{GCV} = \frac{W(t_2 - t_1)}{V} \text{ cal/lit or kcal/m}^3$$

$$\& \text{NCV} = \text{GCV} - \frac{m}{V} \times 587 \text{ in}$$

where,

$W$  = wt of water in cu coil

$V$  = Vol<sup>m</sup> of gaseous fuel

$t_1$  = temp. of inlet water

$t_2$  = outlet temp.

$m$  = mass of steam condensed

### Numerical →

- Q. In a Boy's gas calorimeter, a gaseous fuel was burnt & following data was obtained -
- Vol<sup>m</sup> of gas burnt =  $0.1 \text{ m}^3$  at STP
- Weight of water heated =  $10 \text{ kg}$
- Temp. of inlet water =  $22^\circ\text{C}$
- Temp. of outlet water =  $34^\circ\text{C}$
- Wt of steam condensed =  $0.025 \text{ kg}$
- Cal. gross & net calorific values of fuel.
- Assume latent heat of steam formed as  $580 \text{ kcal/kg}$ .

→ Given: -  $V = 0.1 \text{ m}^3$

$m = 10 \text{ kg}$ ,  $t_1 = 22^\circ\text{C}$ ,  $t_2 = 34^\circ\text{C}$ ,

$m = 0.025 \text{ kg}$ , Latent heat =  $580 \text{ kcal/kg}$

$$\begin{aligned} \text{GCV} &= \frac{W(t_2 - t_1)}{V} \\ &= \frac{10(34 - 22)}{0.1} \\ &= 1200 \text{ kcal/m}^3 \end{aligned}$$

$$\begin{aligned} \text{NCV} &= \text{GCV} - \frac{m}{V} \times \text{Latent heat of steam} \\ &= 1200 - \frac{0.025}{0.1} \times 580 \end{aligned}$$

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Ques. The following observations were noted in Boy's Gas Calorimeter expt. on a gaseous fuel-

Vol<sup>cm</sup> of gas burnt at STP =  $0.08 \text{ m}^3$

Mass of cooling water =  $30 \text{ kg}$ ,

Rise in temperature of water =  $8.2^\circ\text{C}$

Mass of steam condensed =  $0.04 \text{ kg}$

Calculate GCV & NCV of the fuel.

⇒

$$\text{GCV} = 3075 \text{ kcal/m}^3$$

$$\text{NCV} = 2781.5 \text{ kcal/m}^3$$

\* Solid Fuel :- Coal

- Coalification - Def<sup>n</sup> - It is the process of formation of coal underground by the reaction of temp., pressure, bacteria under certain favourable conditions.
- Classification of Coal -  
Wood → Peat → Lignite → Bituminous → Anthracite

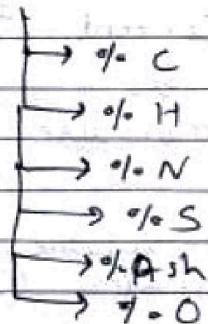
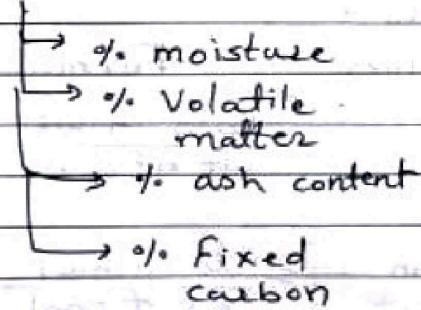
From Peat to Anthracite, % Carbon, CV increases whereas % moisture, % volatile matter, % Ash decreases.

\* Analysis of Coal :-

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Proximate

Ultimate / Elemental



$$\% FC = 100 - (\% \text{ moisture} + \% \text{ volatile matter} + \% \text{ Ash})$$

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

### A] Proximate Analysis of coal :-

Def<sup>n</sup>- It includes determination of % moisture, % volatile matter, % ash content & % fixed carbon from coal.

Procedure - Weigh 1 gm of coal sample in already weighed silica crucible. For % moisture, keep it into oven, without lid for 1 hr by maintaining temp.  $110^{\circ}\text{C}$ . After 1 hr, take out crucible & cool it in desiccator. Repeat the process till const. loss in wt is found. Then, for % Volatile matter, repeat this process with lid with same sample for 7 min at  $925^{\circ}\text{C}$ . Also repeat for % ash content without lid for V.B.P. Patil, At MCGE, Purle from above data, calculate % FC.

#### Summary & calculations -

Content Temp. Duration Formula

$$1) \% \text{ moisture } 105^{\circ}\text{C} \quad 1 \text{ hr} \quad = \frac{\text{loss in wt}}{\text{wt of coal}} \times 100$$

$$2) \% \text{ volatile matter } 925^{\circ}\text{C} \quad 7 \text{ min} \quad = \frac{\text{loss in wt}}{\text{wt of coal}} \times 100$$

For moisture free sample

$$\% V = \left[ \frac{\text{loss in wt}}{\text{wt of coal}} \times 100 \right] - \% \text{ H}_2\text{O}$$

$$3) \% \text{ Ash } 700 \pm 50^{\circ}\text{C} \quad 30 \text{ min} \quad \% \text{ Ash} = \frac{\text{wt of ash}}{\text{wt of coal}} \times 100$$

$$4) \% \text{ FC} = 100 - (\% \text{ moisture} + \% \text{ volatile matter} + \% \text{ Ash})$$

- Significance of Proximate Analysis -
  - i) % Moisture - It should be less as it decreases CV of fuel & increases storage-transportation problem.
  - ii) % Volatile matter - It should be less as it decreases CV of fuel & increases pollution problem, also it burns with long & smoky flame.
  - iii) % Ash - It should be less as it decreases CV of the fuel & also ash disposal is a big problem.
  - iv) % Fixed Carbon - It should be higher as it increases CV.

Quality of coal becomes good when % FC is more while % moisture, % volatile matter, % ash content is less in the fuel/coal.

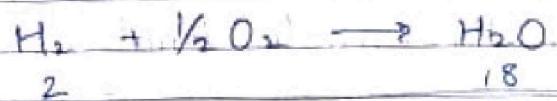
### B] Ultimate Analysis :- (Elemental Analysis)

Defn - It includes determination of % C, % H, % N, % S, % O, % Ash from the coal.

#### i) Determination of % C & % H -

(Combustion tube method) -

Principle - A known wt of coal is burnt in presence of  $O_2$ . C & H present in coal get converted into  $CO_2$  &  $H_2O$  respectively. From wt of  $H_2O$  &  $CO_2$  formed, amount of % C & % H can be calculated.



$$\% \text{ H} = \frac{2}{18} \times \frac{\text{wt of H}_2\text{O}}{\text{wt of coal}} \times 100$$

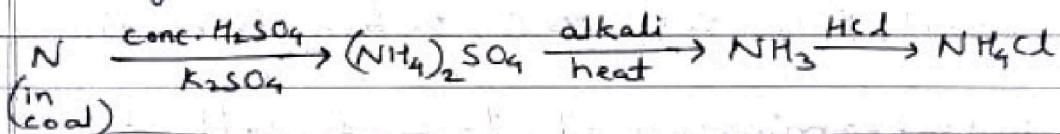


$$\% C = \frac{12}{44} \times \frac{\text{wt of } CO_2}{\text{wt of coal}} \times 100$$

## 2) Determination of % N -

(Kjeldahl's method)

Using Kjeldhal's flask, Nitrogen from coal is treated with  $H_2SO_4$  in presence of  $K_2SO_4$  is converted into  $(NH_4)_2SO_4$  which on boiling with alkali liberates  $NH_3$  & this  $NH_3$  is absorbed in acid. Thus, amount of Nitrogen is calculated.



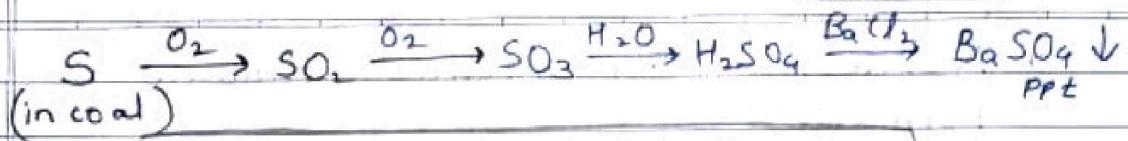
$$\% \text{ N} = \frac{\text{Vol}^m \text{ of acid used (for neutralization of ammonia)}}{\text{wt of coal taken}} \times \text{Normality of acid} \times 1.4$$

### 3) Determination of % S :-

( Eschka Method )

Sulphur in coal is combusted to give  $\text{SO}_2$  &  $\text{SO}_3$  which is absorbed in water to give sulphates which are treated with  $\text{BaCl}_2$  &  $\text{BaSO}_4$  ppt is formed. From wt of  $\text{BaSO}_4$ , % S can be calculated.

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$$\% \text{ S} = \frac{32}{233} \times \frac{\text{wt of BaSO}_4}{\text{wt of coal}} \times 100$$

#### 4) Determination of % Ash by Proximate Analysis -

$$\% \text{ Ash} = \frac{\text{wt of ash formed}}{\text{wt of coal}} \times 100$$

#### 5) Determination of % O<sub>2</sub> -

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

- Significance of Ultimate Analysis :-

i) Higher the % C & H, better the quality of coal.

ii) Lesser the % N, better the quality of coal.

iii) \_\_\_\_\_ % S, \_\_\_\_\_

iv) \_\_\_\_\_ % O, \_\_\_\_\_

v) \_\_\_\_\_ % Ash, \_\_\_\_\_

- Nitrogen - has no calorific value, hence its presence in coal is undesirable.

- Sulphur in coal causes atmospheric pollution

- Ash reduces calorific value of coal

air

O<sub>2</sub>H to H<sub>2</sub>O → 2 H<sub>2</sub>

CO<sub>2</sub> to CO → 2 C

(so)

## \* Numerical on Ultimate Analysis -

Formulae -

$$\% C = \frac{12}{44} \times \frac{\text{wt of } CO_2}{\text{wt of } H_2O} \times 100$$

$$\% H = \frac{2}{18} \times \frac{\text{wt of } H_2O}{\text{wt of coal}} \times 100$$

$$\% N = \frac{(V_2 - V_1) \times \text{Normality of acid}}{\text{wt of coal}} \times 1.4$$

$$\% S = \frac{32}{233} \times \frac{\text{wt of } BaSO_4}{\text{wt of coal}} \times 100$$

$$\% \text{ Ash} = \frac{\text{wt of ash}}{\text{wt of coal}} \times 100$$

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

Ques. 0.25 g of coal sample on burning in a combustion chamber in a current of oxygen increased the weight of  $CaCO_3$  U-tube by 0.18 g &  $KOH$  U-tube by 0.69 g. Find % C & % H in coal.

Given  $\rightarrow$  wt of coal = 0.25 g

wt of  $CO_2$  = 0.69 g ( $KOH$  U-tube)

wt of  $H_2O$  = 0.18 g ( $CaCO_3$  U-tube)

$$\begin{aligned} \% C &= \frac{12}{44} \times \frac{\text{wt of } CO_2}{\text{wt of coal}} \times 100 = \frac{12}{44} \times \frac{0.69}{0.25} \times 100 \\ &= \underline{\underline{75.27 \%}} \end{aligned}$$

$$\begin{aligned} \% H &= \frac{2}{18} \times \frac{\text{wt of } H_2O}{\text{wt of coal}} \times 100 = \frac{2}{18} \times \frac{0.18}{0.25} \times 100 \\ &= \underline{\underline{8.00 \%}} \end{aligned}$$

Ques. 1.5 g of coal in Kjeldahl's experiment liberated ammonia which was absorbed in 50 ml 0.1 N H<sub>2</sub>SO<sub>4</sub>. The remaining acid required 9.1 ml of 0.1 N NaOH for complete neutralisation. Calculate % of nitrogen in coal.

Given - wt of coal = 1.5 g

Normality of acid, N = 0.1 N

titration reading, V<sub>1</sub> = 9.1 ml

Blank ——————, V<sub>2</sub> = 50 ml

$$\% \text{ N} = \frac{(V_2 - V_1) \times N \times 1.4}{\text{wt of coal}} \\ = \frac{(50 - 9.1) \times 0.1 \times 1.4}{1.5} = \underline{\underline{3.81 \%}}$$

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Ques. 2.50 g of coal in quantitative analysis gave 0.23 g of BaSO<sub>4</sub>. Calculate % of sulphur in coal.

Given - wt of coal = 2.50 g

wt of BaSO<sub>4</sub> = 0.23 g

$$\% \text{ S} = \frac{32}{233} \times \frac{\text{wt of BaSO}_4}{\text{wt of coal}} \times 100 \\ = \frac{32}{233} \times \frac{0.23}{2.50} \times 100 = \underline{\underline{1.26 \%}}$$

Ques. Calculate % O from the coal, if it contains % C = 75.27, % H = 8, % N = 3.81, % S = 1.26 %.

Given - % C = 75.27, % H = 8, % N = 3.81, % S = 1.26, % Ash = not given, hence = % O (100)

$$\% \text{ O} = 100 - (\% \text{ C} + \% \text{ H} + \% \text{ N} + \% \text{ S} + \% \text{ Ash}) \\ = 100 - (75.27 + 8 + 3.81 + 1.26 + 0)$$

$$= \underline{\underline{11.66 \%}}$$

**Ques.** 1.3 g of coal sample was burnt in oxygen.  $\text{CO}_2$  was absorbed in KOH & water vapour in  $\text{CaCl}_2$ . The increase in weight of KOH &  $\text{CaCl}_2$  was 2.876 & 0.403 g respectively. Determine %C & %H in the sample.

**Ques.** 1.56 g of the coal was Kjeldahlised &  $\text{NH}_3$  gas thus evolved was absorbed in 50 ml 0.1 N HCl. After absorption acid required 6.25 ml of 0.1 N NaOH for neutralisation. 2.60 g of coal sample in quantitative analysis gave 0.1755 g  $\text{BaSO}_4$ . Calculate %N & %S.

**Ques.** Calculate V.N.Patil, MMGCE, Pune from the coal from following data -

- 0.15 g coal sample on burning in combustion chamber in the current of pure  $\text{O}_2$ , was found to increase wt of  $\text{CaCl}_2$  U-tube by 0.08 gm & KOH U-tube by 0.49 gm.
- 0.65 g coal was combusted in Bomb Calorimeter. Soln from Bomb pot on treatment with BaCl<sub>2</sub> soln, forms 0.031 g  $\text{BaSO}_4$  dry ppt.
- 1.6 g of coal in Kjeldahl's expt liberated  $\text{NH}_3$  which was absorbed in 50 ml  $\text{H}_2\text{SO}_4$ . The resultant soln required 14 ml of 0.1 N NaOH for complete neutralization of  $\text{H}_2\text{SO}_4$  in back titration. The reading for blank titration was 25 ml. Find % nitrogen in coal.

## Numericals on Proximate Analysis :- Formulae -

i) % H<sub>2</sub>O =  $\frac{\text{loss in wt or wt of moisture}}{\text{wt of coal}} \times 100$

ii) % Volatile Matter =  $\frac{\text{loss in wt or wt of VM matter}}{\text{wt of coal (initial)}} \times 100$

For Air dried coal sample -

$$\% \text{ VM} = \left[ \frac{\text{loss in wt}}{\text{wt of coal}} \times 100 \right] - \% \text{ H}_2\text{O} (\text{Moisture})$$

iii) V.N.Patil, MMCOE, Pune

$$\% \text{ Ash} = \frac{\text{wt of ash}}{\text{wt of coal}} \times 100$$

iv) % FC =  $100 - (\% \text{ H}_2\text{O} + \% \text{ VM} + \% \text{ Ash})$   
(fixed carbon)

Numericals -

- i) 2.00 g coal sample was heated for one hour at 110°C, the weight of the residue was 1.80 g. The residue was then covered with a vented lid and heated for exactly 7 mins at 950°C. The residue weighed 1.00 g. The crucible was then heated without lid till a constant weight of the residue of 0.15 g was obtained. Calculate % of the various constituents of coal. [4]

→ Given → wt of coal = 2.00 g  
 after 1 hr = 1.80 g  
 i.e. loss in wt =  $(2 - 1.80)$  - For % H<sub>2</sub>O  
 after 7 mins = 1.00 g  
 i.e. loss in wt =  $(1.80 - 1)$  - For % VM  
 wt of ash = 0.15 g. - For % Ash

i) % H<sub>2</sub>O =  $\frac{\text{loss in wt}}{\text{wt of coal}} \times 100$   
 $= \frac{(2 - 1.80)}{2} \times 100 = \underline{\underline{10\%}}$

ii) % VM =  $\frac{\text{loss in wt}}{\text{wt of coal}} \times 100$

V.N.Patil, MAMCOE, Pune 40 %

iii) % Ash =  $\frac{\text{wt of ash}}{\text{wt of coal}} \times 100$   
 $= \frac{0.15}{2} \times 100 = \underline{\underline{7.5\%}}$

iv) % Fixed Carbon =  $100 - (\% \text{ H}_2\text{O} + \% \text{ VM} + \% \text{ Ash})$   
 $= 100 - (10 + 40 + 7.5)$   
 $= \underline{\underline{42.5\%}}$

2) 1.2 g coal sample was heated in a crucible in an oven at  $110^{\circ}\text{C}$  for 60 min. The weight of the residue was  $\frac{1.16}{1.169}$  g then burnt completely to a const. weight of 0.09 g. In another expt., 1.2 g of same coal sample was heated in a crucible with <sup>verified</sup> lid at  $950^{\circ}\text{C}$  for 7 min. After cooling the weight of the residue was 0.8 g. Calculate the % result.

$$\text{Given} \rightarrow \text{wt of coal} = 1.2 \text{ g.}$$

$$\text{after } 110^{\circ}\text{C} = 0.09 \text{ g.}$$

$$\therefore \text{loss in wt.} = (1.2 - 1.16) \text{ g} \quad \text{for \% H}_2\text{O}$$

$$\therefore \text{wt of ash} = 0.09 \text{ g.}$$

$$\text{wt of coal} = 1.2 \text{ g.}$$

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$$\therefore \text{loss in wt} = (1.2 - 0.8) \text{ g} \quad \text{for \% Vm.}$$

$$\text{i) \% H}_2\text{O} = \frac{\text{loss in wt}}{\text{wt of coal}} \times 100 = \frac{(1.2 - 1.16)}{1.2} \times 100 = \underline{\underline{3.33\%}}$$

$$\text{ii) \% Ash} = \frac{\text{wt of ash}}{\text{wt of coal}} \times 100 = \frac{0.09}{1.2} \times 100 = \underline{\underline{7.50\%}}$$

$$\begin{aligned} \text{iii) \% Vm} &= \left( \frac{\text{loss in wt}}{\text{wt of coal}} \times 100 \right) - \% \text{H}_2\text{O} \\ &= \left[ \frac{(1.2 - 0.8)}{1.2} \times 100 \right] - 3.33 \\ &= \underline{\underline{30.03\%}} \end{aligned}$$

$$\text{iv) \% FC} = 100 - (\% \text{H}_2\text{O} + \% \text{Vm} + \% \text{Ash})$$

$$(\text{fixed carbon}) = 100 - (3.33 + 30.03 + 7.50)$$

$$= \underline{\underline{59.17\%}}$$

3) Calculate % FC from following data -

1.9 gm coal sample loses 0.285 gm at  $110^{\circ}\text{C}$ . 1.5 gm of same coal sample loses 0.360 gm at  $925^{\circ}\text{C}$ . 2.15 g of coal sample leaves 0.26 g. ash.

Given  $\rightarrow$  i) wt of coal = 1.9 g.

$$\text{wt of H}_2\text{O} = 0.285 \text{ g.}$$

$$\text{i)} \text{wt of coal} = 1.5 \text{ g.}$$

$$\text{wt of VM} = 0.360 \text{ g.}$$

$$\text{ii)} \text{wt of coal} = 2.15 \text{ g.}$$

$$\text{wt of ash} = 0.26 \text{ g.}$$

i)

$$\% \text{H}_2\text{O} = \frac{\text{wt of H}_2\text{O}}{\text{wt of coal}} \times 100 = \frac{0.285}{1.9} \times 100$$

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$$\begin{aligned} \text{i)} \% \text{VM} &= \left[ \frac{\text{wt of VM}}{\text{wt of coal}} \times 100 \right] - \% \text{H}_2\text{O} \\ &= \left[ \frac{0.360}{1.5} \times 100 \right] - 15 \\ &= 9 \% \end{aligned}$$

$$\begin{aligned} \text{iii)} \% \text{Ash} &= \frac{\text{wt of ash}}{\text{wt of coal}} \times 100 = \frac{0.26}{2.15} \times 100 \\ &= 12.09 \% \end{aligned}$$

$$\begin{aligned} \text{iv)} \% \text{FC} &= 100 - (\% \text{H}_2\text{O} + \% \text{VM} + \% \text{Ash}) \\ &= 100 - (15 + 9 + 12.09) \\ &= 63.91 \% \end{aligned}$$

\* Liquid Fuel :- Petroleum / Crude oil

Petroleum is a dark, greenish-brown viscous oil.

Refining - It is the process in which petroleum or crude oil is separated into its components by fractional distillation also it separates impurities.

Three steps in refining -

- 1) Removal of water (by Cottrell's process)
- 2) Removal of Harmful sulphur components (by using copper oxide)
- 3) Fractional Distillation.

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Principal - It is the process of separation of various components from crude oil using distillation column on the basis of boiling points of fractions i.e. high B.P. con fractions condensed first (into liquid) during this process.

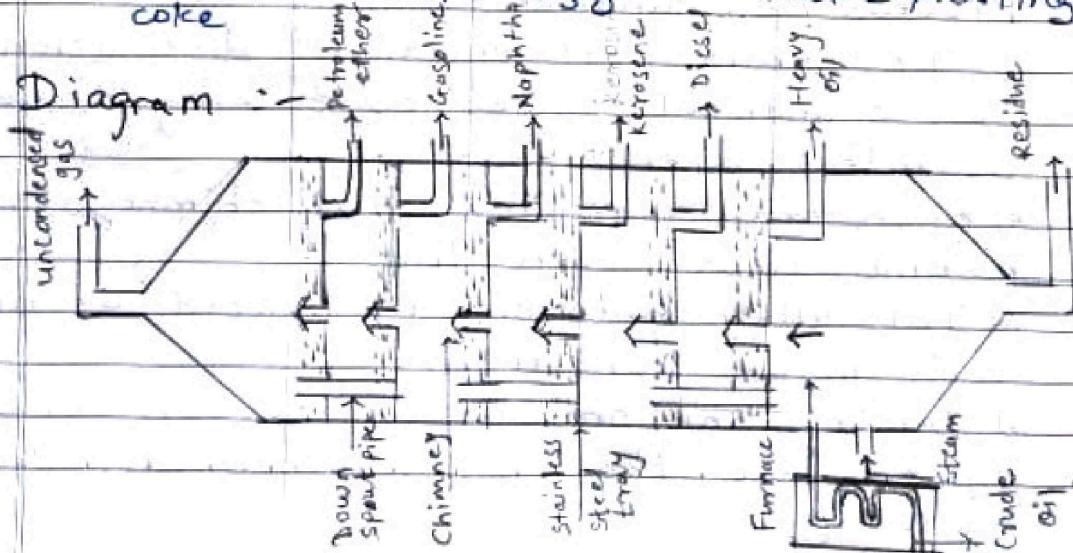
Process / Explanation -

- i) It consists of fractional distillation column, tall cylindrical tower containing no. of stainless steel trays.
- ii) Each tray contains small chimneys i.e. bubble caps with lids.
- iii) Initially crude oil is heated at about  $400^{\circ}\text{C}$  in an iron retort.
- iv) During the process, vapours pass through pipes where they cool & condensed, collected separately.

### Various Fractions -

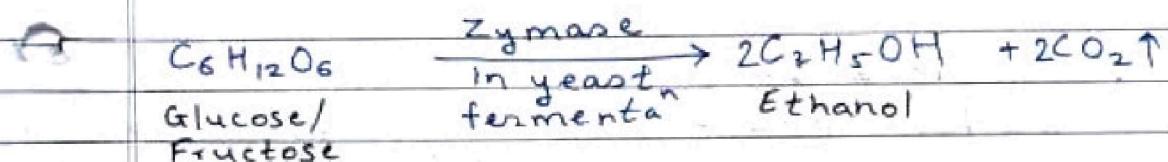
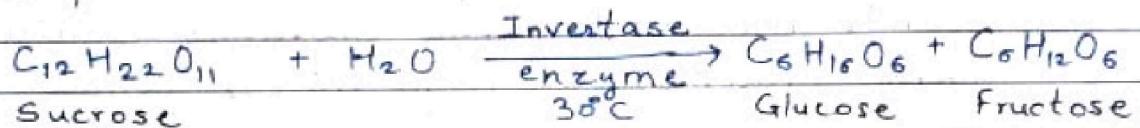
Name of fractions	Temp. range	Composition	Uses
Uncondensed gases	below $30^{\circ}\text{C}$	$\text{C}_1\text{-C}_4$	Domestic & Industrial use as LPG
Petroleum ether	$40\text{-}70^{\circ}\text{C}$	$\text{C}_5\text{-C}_7$	Fuel for aeroplane, helicopters as solvent
Gasoline / Petrol	$60\text{-}120^{\circ}\text{C}$	$\text{C}_5\text{-C}_8$	Fuel for petrol engine, dry cleaning as solvent.
Naphtha / Solvent spirit	$120\text{-}180^{\circ}\text{C}$	$\text{C}_7\text{-C}_{10}$	As solvent & for dry cleaning chemical
Kerosene	$280\text{-}250^{\circ}\text{C}$	$\text{C}_{10}\text{-C}_{16}$	For illumination, domestic fuel
Diesel	$250\text{-}320^{\circ}\text{C}$	$\text{C}_5\text{-C}_8$	Domestic fuel for vehicles
Heavy oil		$\text{C}_{18}\text{-C}_{20}$	Lubrication.
-i) lubricating oil		$\text{C}_{20}\text{-C}_{22}$	candles, boot polish, medicines
ii) Petroleum jelly,		$\text{C}_{22}\text{-C}_{26}$	
iii) grease, wax		$\text{C}_{26}\text{-C}_{30}$	
Residue - asphalt, petroleum coke	$>400^{\circ}\text{C}$	above $\text{C}_{30}$	road making, water proofing roofs.

Diagram :-



\* Power Alcohol :-

- Def<sup>n</sup>- When ethanol is blended with petrol (20-25 %) & is used as a fuel for internal combustion engines, it is called as 'power alcohol'.
  - Preparation of ethanol :-



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Explanation:- When sucrose (from molasses) is converted into glucose & fructose with the help of invertase, at  $30^{\circ}\text{C}$  & water.

This glucose/fructose is treated with zymase from yeast to give ethyl alcohol &  $\text{CO}_2$  by fermentation.

## Advantages

## Disadvantages

- i) Ethanol has high octane numbers (90) than petrol (7000 cal/g) than petrol (60-70).      ii) Ethanol has low cv numbers (7000 cal/g) than petrol (11,500 cal/g).
  - iii) Ethanol is a renewable source of energy.
  - iv) It causes starting trouble.
  - v) Ethanol absorbs moisture from petrol.
  - vi) As it undergoes oxid<sup>n</sup>, it may corrode engine parts.
  - vii) It burns clean, & reduces emission of harmful gases.
  - viii) Carburettor or engine need to be modified.
  - ix) Reduces dependency on foreign currency.
  - x) Dry ethanol is costly.

\* Gaseous Fuels →

- High cv, burns clean with no pollution.
- Highly inflammable, causes storage problem.

\* CNG (Compressed Natural Gas) -

• Composition -

→ 70-90% Methane, 10-20% ethane,  
2-8% propane & other hydrocarbons upto  
 $C_5$ ,  $CO_2$ ,  $NH_3$ ,  $H_2O$ , etc.

• Properties -

- i)  $cv = 13000 \text{ kcal/m}^3$
- ii) Complete combustion
- iii) No pollution like  $CO$ ,  $SO_x$ , particles.
- iv) Safer to use.

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v) It mixes better with air than lq. fuels.

• Uses/ Applications -

- i) As automobile fuel
- ii) Industrial fuel
- iii) As a raw material for Carbon black & Hydrogen gas.
- iv) Useful for manufacturing of methanol, formaldehyde, etc.

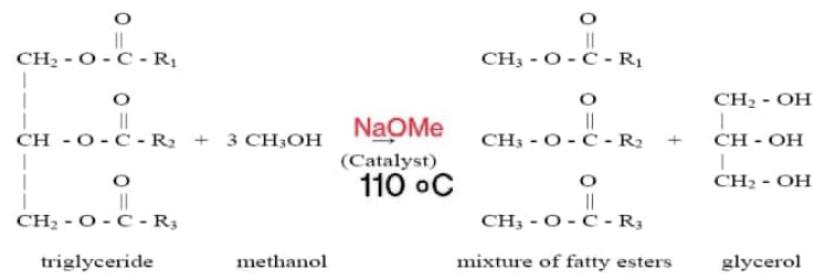
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### \* Bio-diesel :-

- Def<sup>n</sup> - It is methyl ester of long chain fatty acids formed by transesterification process. (Transesterification Process - converting one ester to another ester).

When vegetable / animal oil is treated with methanol using catalyst sodium methoxide ( $\text{NaOMe}$ ) at temp.  $110^\circ\text{C}$ , yellow coloured biodiesel is formed <sup>along</sup> with water soluble glycerol.

### Reaction



Transesterification Reaction

### Explanation.

- Filter cheap veg. oil / animal fat & heat at  $110^\circ\text{C}$  with stirring
- Add 2%  $\text{NaOMe}$  & 20% methanol to it
- Reflux the mixture for 30 min. at  $60-70^\circ\text{C}$
- Thus, yellow coloured biodiesel (water insoluble) with water soluble glycerol is formed.

### Advantages

- Regenerative & envt friendly
- Reduces dependancy on foreign currency & countries <sup>too</sup>.
- Good lubricity.
- non-toxic free from Sulphur.
- Good solvent.

### Disadvantages

- Currently more costly.
- Storage & transport problem (costly).
- Not compatible with some rubber hoses, gaskets, some metals, plastics.

\* Hydrogen Gas :-

\* H<sub>2</sub> gas as a future fuel -

- i) It has high CV as compared to fossil fuels.
- ii) H<sub>2</sub> is the most abundant (available) element on earth.
- iii) It is non-toxic & clean burning.
- iv) Fuel cells are formed by combination of H<sub>2</sub> & O<sub>2</sub> from air <sup>to produce</sup> into H<sub>2</sub>O & electrical energy.
- v) It is a zero emission fuel when burned with O<sub>2</sub>.

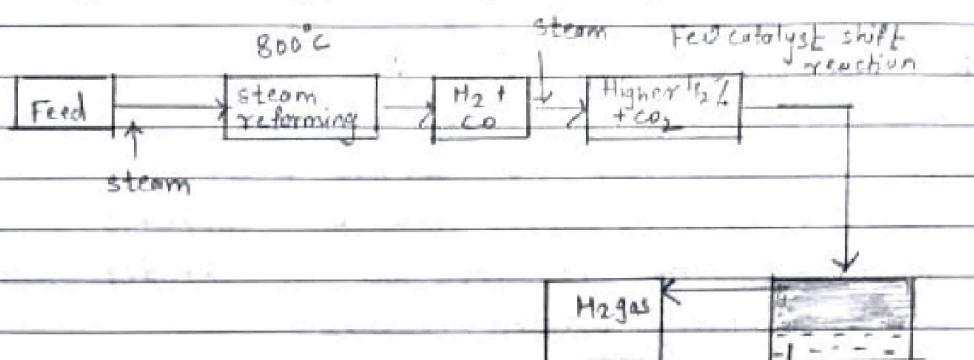
\* Difficulty in Storage & Transportation of H<sub>2</sub> gas :-

- i) Due to highly inflammable nature, H<sub>2</sub> gas is highly risky to store & transport.
- ii) It is the lightest gas, hence it is to be stored in cylinders in compressed form. (<sup>but</sup> Cost of compression is high).
- iii) Decarburation (reduction of green house gas i.e. CO<sub>2</sub>) of H<sub>2</sub> gas in steel cylinder makes steel brittle, may result in explosion.
- iv) It is very difficult to liquify. B.P. = B.P. = -252.6 °C.
- v) It can be stored in liq. form. & transported in cryogenic tanks. (costly method).

\* Production of Hydrogen by Steam reforming of methane & coke :-

A) Steam Reforming of Methane -

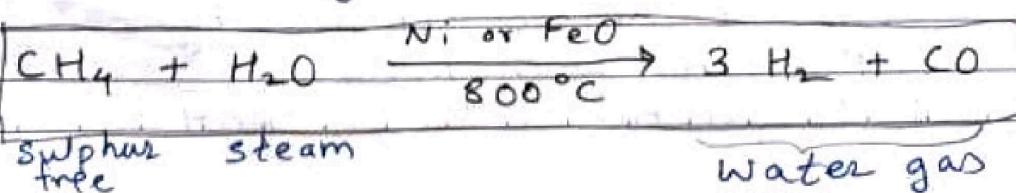
It is the process of reacting steam with hydrocarbons in presence of catalyst of high temp. to produce H<sub>2</sub> & CO<sub>2</sub>.



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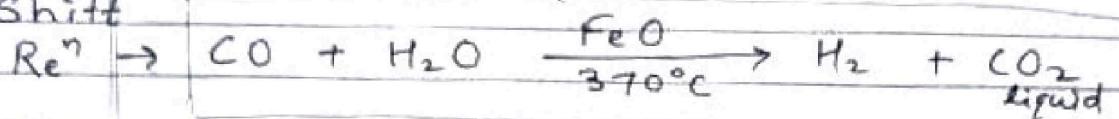
- Feed → CH<sub>4</sub> (Sulphur free natural gas)
- Catalyst → For steam reforming = Ni or FeO  
For shift reaction = FeO
- Temp. → For shift steam reforming = 800°C  
For shift reaction = 370°C
- Pressure → less than 1 atm.

Hydrocarbons like CH<sub>4</sub> from natural gas is mixed with steam (H<sub>2</sub>O) & passed over Ni or FeO catalyst at 800°C temp. to form water gas (mixture of CO + H<sub>2</sub>)



Water gas (mixture of  $\text{CO} + \text{H}_2$ ) is treated with again steam ( $\text{H}_2\text{O}$ ) in presence of  $\text{FeO}$  catalyst at about  $370^\circ\text{C}$  temp. to produce more  $\text{H}_2$  with liquified  $\text{CO}_2$ .

Shift



\* Removal of  $\text{CO}_2$  :- (Any two ways)

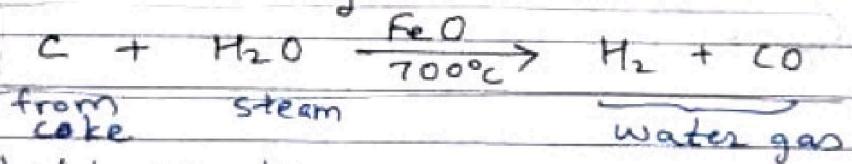
$\text{CO}_2$  can be removed by -

- i) Evaporation re<sup>n</sup> with  $\text{KOH}$
- ii) Scrubbing with alkali solvent.
- iii) Dissolving it in water under pressure
- iv) Reacting with  $\text{K}_2\text{CO}_3$ .

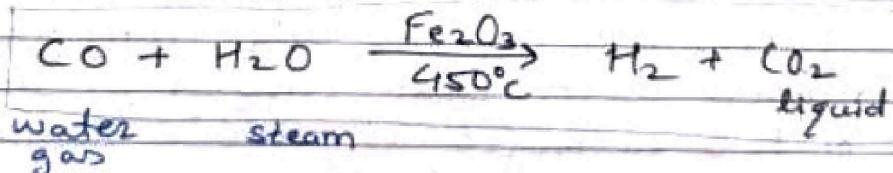
### B) Steam Reforming of Coke

Coke on heating with steam produces water gas at about  $700^\circ\text{C}$  temp. which is then treated with more steam to produce additional  $\text{H}_2$  by shift reaction.

Steam reforming re<sup>n</sup> of coke -



Shift reaction -



$\text{CO}_2$  (l) can be removed by -

- i) Reacting with  $\text{K}_2\text{CO}_3$
- ii) Evaporation re<sup>n</sup> with  $\text{KOH}$ .