

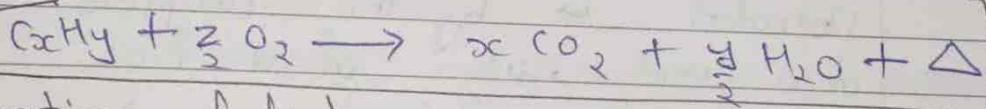
## Fuel

Fuel  $\rightarrow$  Fuel is a **combustible** substance, which contains carbon as a main constituent, which on proper burning gives large amount of heat, which can be used **economically** for domestic and industrial purpose.

fossil fuel  $\rightarrow$  is a general term for buried combustible geologic deposits of organic materials formed from decayed plants and animals that have been converted to crude oil, coal, natural gas.

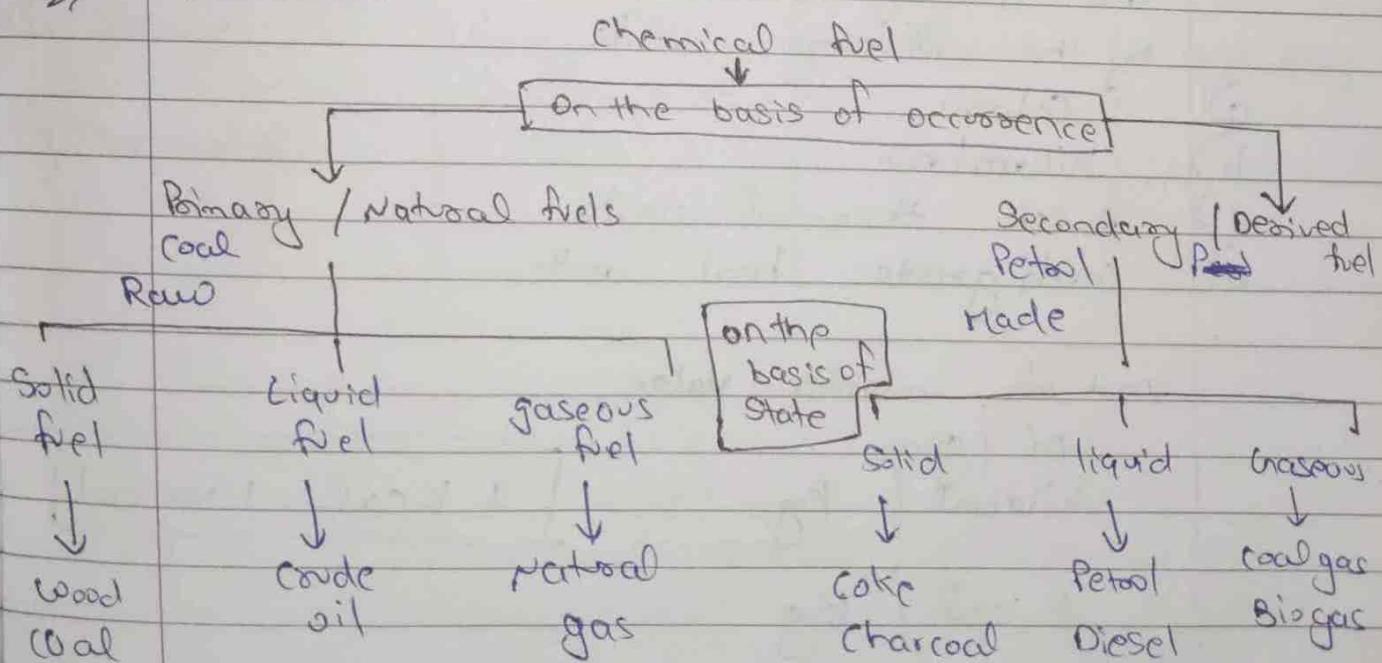
Nuclear fuel  $\rightarrow$  It is fuel that is used in a Nuclear reactor to sustain a nuclear chain reaction.

Combustion



WR

Classification of fuel



Composition of **Producers gas**  $\rightarrow$   $CO + N_2$

**Steam / water gas**  $\rightarrow$   $CO + H_2$

## Characteristics of good fuel

- 1) High calorific value
- 2) Moderate Ignition temperature (में इसका good reason है कि criteria नियमों की)
- 3) Low content of non-combustible Matter
- 4) Low Moisture content
- 5) Easy to transport
- 6) Easy storage
- 7) It should be efficient
- 8) Economical
- 9) CP (Combustion product) like ash residue left after combustion so we acquire low @. CP.

### Calorific value

Calorific value is the amount of heat liberated by the complete combustion of a unit mass of a fuel.

The quantity of heat can be measure by the following units

- a) Calorie
- b) Kilocalorie
- c) British thermal units
- d) centigrade heat units

### Unit of calorific value

cal / gram

kilocal / kg

$$1 \text{ Kcal} = 1000 \text{ cal}$$

K cal / Kg

cal / cc

## Comparative Study of Solid, liquid , gaseous fuel

fuel characteristics	Solid	Liquid	Gas
① Calorific value	least	Highest	Highest
② Combustion rate	slow	Quick	very rapid
③ Combustion control	Not easy	Controllable	Controllable
④ Smoke	Invariably produced (yes)	less	No smoke
⑤ Ash	yes	No	No
⑥ Risk of fire hazards	least	greater	very High
⑦ Cost	cheapest	Moderate	expensive
⑧ Storage	easy	not easy	Not easy
⑨ Transportation cost	High	Low	low

~~GCV > NCV~~

~~WZ~~ Higher or Gross calorific value (HCV / GCV)  
It is the total amount of heat liberated when unit mass or unit volume of the fuel has been burnt completely and the product of combustion are cooled to room temperature.

- Total amount of heat
- GCV → latent heat of vaporization
- High calorific value (latent heat of water included)
- Lower or Net calorific value (Lcv / Ncv)
- It is the net heat produced when unit mass or unit volume of the fuel is burnt completely and the combustion product are allowed to escape.
- Total heat taken out by combustion product.
- Lower calorific value (latent heat subtracted from gross)

~~$$NCV = GCV - q \times \text{wt of hydrogen} \times 587 \text{ cal/g}$$~~

when wt of hydrogen = 0  
when no hydrogen in fuel

$$NCV = GCV - q \times 0 \times 587$$

$$NCV = GCV$$

British Thermal Unit (B.Th.U or BTU) It is the quantity of heat required to increase the temperature of 1 pound of water through 1° Fahrenheit

$$1 \text{ B.Th.U} \rightarrow = 252 \text{ cal} = 0.252 \text{ kcal}$$

$$1 \text{ kcal} = 3.968 \text{ B.Th.U} = 2.3 \text{ CHU}$$

(c) Solid fuel has calorific value 9000 cal/g  
Express in British Thermal unit.

Sol)

$$1 \text{ BTU} = 252 \text{ calories}$$

$$\frac{1}{252} \text{ BTU} = 1 \text{ calorie}$$

$$\frac{9000}{252} \text{ BTU} = 9000 \text{ calories}$$

9000	BTU
252	

Bomb calorimeter

Determination of calorific value of solid fuel / non volatile fuel by Bomb calorimeter

Calorimeter  $\rightarrow$  It is a device which is used to calculate the calorific value.

Bomb calorimeter  $\rightarrow$

A Bomb calorimeter is a constant-volume calorimeter, constructed to withstand the pressure produced by the reaction as it heats the air within the container. The temperature change of water is used to calculate the heat of combustion.

Principle

$$\text{Total Heat released} = \text{Total Heat absorbed during combustion}$$

This apparatus is used to calculate the calorific value of solid and non-volatile liquid fuel

A known mass of fuel is burnt in excess of oxygen and heat liberated is transferred to known amount of water.

### Construction

- 1) Stainless steel cylindrical Bomb (pressure inside it is 50 atm) containing.
  - \* fix tight sealed lid \* oxygen inlet
  - \* 2 stainless steel electrode connected to an external battery.
  - \* Small ring attached to one electrode which act as support for crucible
  - \* Crucible containing fuel placed on the small ring Magnesium pt wire.
- 2) Copper Calorimeter  $\rightarrow$  Steel bomb is placed in Copper ~~calorimeter~~ calorimeter containing known amount of water
- \* Beckmann thermometer
- \* Mechanical stirrer
- \* Air jacket
- \* Water jacket

Copper calorimeter is surrounded by this air jacket and water jacket to prevent any loss of heat due to radiation

### Working

A known amount of fuel (0.5 to 1g) is taken in the crucible supported over the ring.

Stretch the fine wire (fine Mg wire) over electrode touching the fuel sample.

Tightly screwed the bomb lid

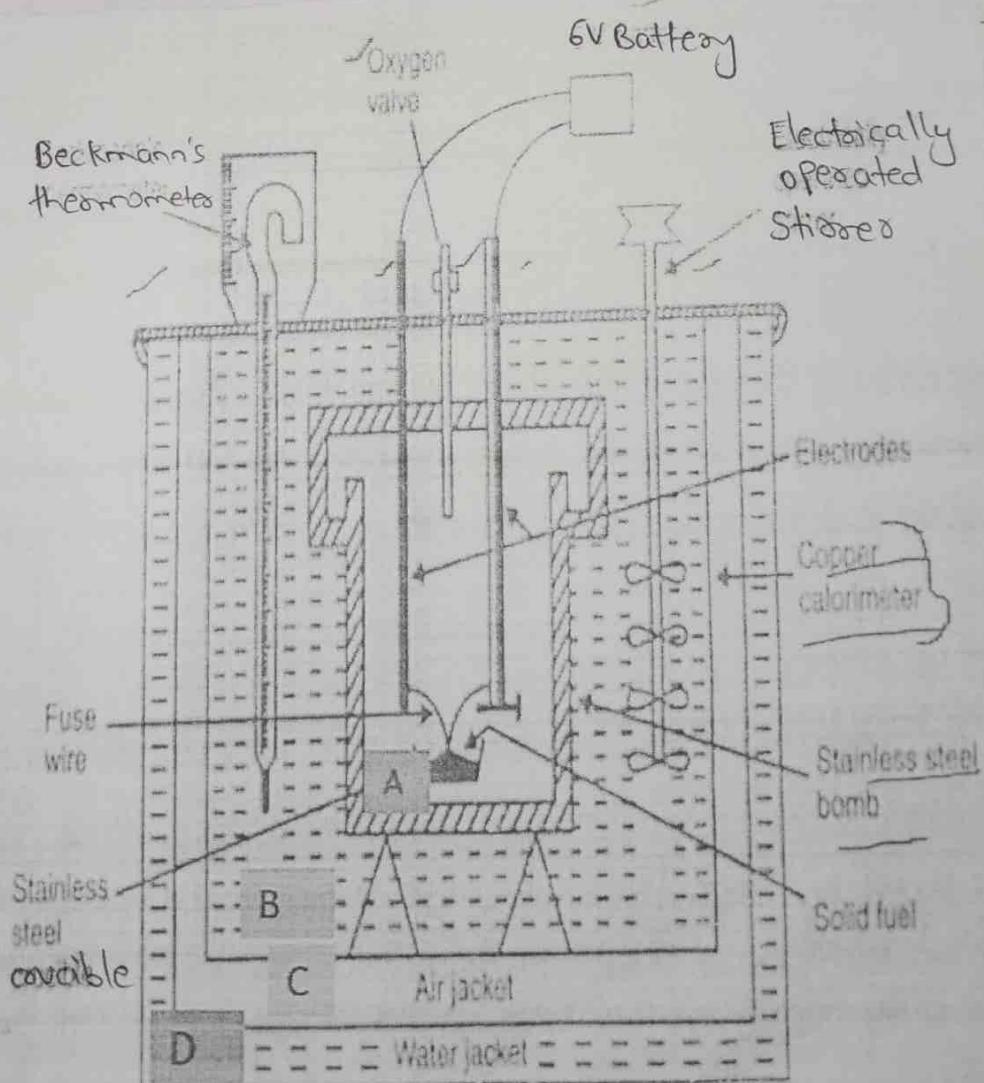
Till the bomb with oxygen to 25-30 atmospheric

pressure  
place the bomb in copper calorimeter containing  
a known amount of water after stirring  
note initial temperature of water with the  
help of Beckmann thermometer.

connect the electrode with 6 volt battery  
and complete the circuit.

Combustion of fuel with release of heat  
Transfer of heat to water present in  
calorimeter

Note the final temperature reading.



Bomb Calorimeter

### Observation

let amount of fuel taken in crucible =  $w$  gram  
 " " " water taken in calorimeter =  $w$  gram  
 " " " water equivalent =  $w$  gram  
 " " calorific value of fuel =  $C$  cal/gm  
 Heat released =  $w \times C$  calories

Initial Temperature =  $T_1$  °C  
 final Temperature =  $T_2$  °C

Heat absorbed by water =  $w \times s \times (T_2 - T_1)$

$$s = 1$$

$$\text{or } s = 1$$

Heat absorbed by water =  $w \times s \times (T_2 - T_1)$

Heat absorbed by water equivalent =  $w \times s \times (T_2 - T_1)$

$s_p$  of water = 1 cal/g °C

Total heat absorb =  $ws(T_2 - T_1) + ws(T_2 - T_1)$

$$= (w+w)(T_2 - T_1)s$$

$$= (w+w)(T_2 - T_1)$$

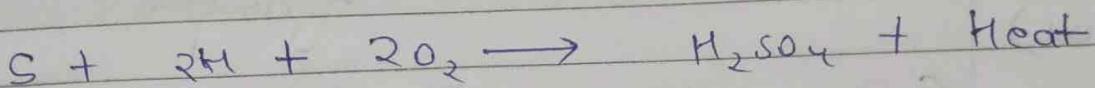
$$wC = (w+w)(T_2 - T_1)$$

$$GCV = C = \frac{(w+w)(T_2 - T_1)}{w}$$

$$NCV = GCV - 9 \times \text{wt of H} \times 587 \text{ cal/gm}$$

Correction in Bomb calorimeter

- Fuse wise correction  $\rightarrow$  Heat released due to ignition of ~~the~~ fuse wire should be subtracted.
- Acid correction  $\rightarrow$  Fuel containing S and N oxidize to  $H_2SO_4$  &  $HNO_3$  under high temperature and pressure of ignition



The amount of these acid ~~calorimeters~~ correction analyzed by washing of the Calorimeter

for each ml of  $\frac{N}{10} H_2SO_4$  formed 3.6 cal this

Should be subtracted.

1 mg of S = 2.52 cal this should be subtracted

1 ml of  $\frac{N}{10} HNO_3$  = 1.43 cal this should be subtracted

c) Cooling correction

$$\text{GCV of fuel (C)} = \frac{(W+\omega)(T_2 - T_1 + \text{cooling correction})}{\text{Mass of fuels}} \quad (\text{Acid + fuse correction})$$

Mass of fuels

(Q) In a Bomb calorimeter experiment the following data were obtained  
 wt of coal = 0.83 g

wt of water taken in calorimeter = 1365 g  
 wt of water equivalent of calorimeter = 135 g

initial T = 26.5 °C

final T = 29.2 °C

calculate the GCV & NCV of fuel if it contains 8% of Hydrogen

(Sol)

$$GCV = \frac{(W+w)(T_2 - T_1)}{SC} \quad \alpha = 0.83$$

$$= \frac{(1365 + 135) \times (29.2 - 26.5)}{0.83}$$

$$= 4879.51 \text{ cal/g}$$

$$NCV = GCV - q \times H \times 587$$

$$= 4879.51 - 9 \times \frac{8}{100} \times 587$$

$$= 4456.87 \text{ cal/g}$$

(Q) A sample of coal contain C = 94%, H = 5%.

Ash = 1%. The following data were obtained when the above coal was tested in bomb calorimeter.

wt of coal = 0.95 g

wt of water taken = 700 g

wt of water equivalent of calorimeter = 2000 g

Increase in Temperature = 2.48 °C

use wise correction = 10.0 ml

acid correction = 60.0 cal

Cooling correction = 0.02 °C

calculate GCV & NCV (Latent heat of condensation of steam = 587 cal/g).

sd) wt of coal (x) = 0.95 g

w = 700

w = 2000

$t_1 - t_2 = 2.48^\circ\text{C}$

fuse wise correction = 10.0 cal

acid correction = 60.0 cal

Cooling correction = 0.02 °C

$\text{GCV} = (w+w) \cdot (t_2 - t_1 + \text{cooling correction}) - (\text{acid} + \frac{\text{fuse}}{\cancel{\text{base}}} \text{ correction})$

Mass of fuel

$$\text{GCV} = \frac{(700 + 2000)(2.48 + 0.02) - (60 + 10)}{0.95}$$

$$= 7031.57 \text{ cal/g}$$

$$\text{NCV} = \text{GCV} - q \times H \times 587$$

$$= 7031.57 - q \times 5 \times \frac{587}{100}$$

$$= 6767.42 \text{ cal/gm}$$

Note

In a bomb calorimeter does the reaction takes place under conditions of

- a) Constant pressure X
- b) Constant volume ✓

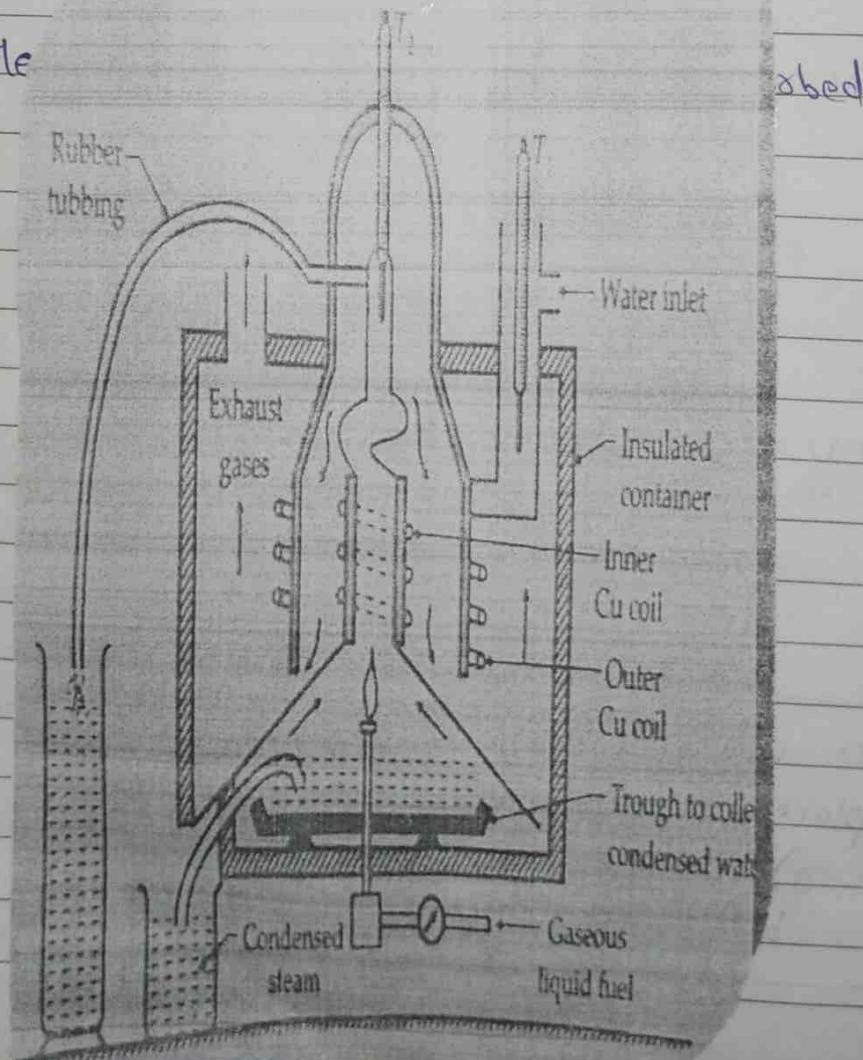
## Boyle's gas calorimeter

It is used for determination of calorific value of gaseous and volatile liquid fuel.

### Principle

The gaseous fuel is burned in a vessel at a constant rate in such a manner that the entire heat is absorbed by water which is circulated in a chimney around the burner. From the volume of the gaseous fuel burnt the volume of water collected and the rise of temperature of water and the calorific value of fuel is determined.

$$\text{Heat lost} = \text{heat gain}$$



## construction

- 1) Gas burner → It consists of suitable gas burner in which a known volume of gas at a known pressure is burnt at a uniform rate.
- 2) Combustion chamber or chimney  
Round the burner there is a chimney or combustion chamber having copper tubing coiled inside as well as outside it. Water at a constant rate enters at the top of the outer coil passes through the outer coil. Moves to the bottom of the chimney and then moves upward through the inner coil and exit from the top.

### 3) Thermometer

The thermometer  $T_1$  &  $T_2$  are fitted to note the temperature of the incoming and outgoing water respectively.

### 4) Container

A container is provided to collect water formed due to condensation of steam produced during combustion.

### 5) Insulated chamber

The whole assembly is enclosed in an insulated chamber.

Burning of fuel and circulation of water are continued for about 15 minutes for initial warming up period.

When the calorimeter get warmed the rates of fuel burning and water circulation are adjusted so that exit water leaves the apparatus nearly at atmospheric pressure

Heat produced by burning of gaseous fuel is transferred to water in the copper coil and the steam formed inside the chimney during combustion gets condensed to water which is collected in the provided container. Readings are noted when conditions become steady.

### Observation

Let volume of gaseous fuel burnt at STP =  $V \text{ m}^3$

Initial Temperature  $t_1 \text{ }^\circ\text{C}$

Final Temperature  $t_2 \text{ }^\circ\text{C}$

wt of water collected =  $w \text{ kg}$

wt of water condensed =  $m \text{ kg}$

Calorific value of fuel =  $C \text{ kcal/m}^3$

Heat released =  $VC \text{ kcal}$

Heat absorbed =  $w \times s \times 0.1(t_2 - t_1)$

$$VC = ws(t_2 - t_1)$$

$$VC = w(t_2 - t_1)$$

~~Given~~ 
$$GCV = C = \frac{w(t_2 - t_1)}{V}$$

$V \text{ m}^3$  of gas =  $m \text{ kg}$  of water  
 $1 \text{ m}^3$  of gas =  $\frac{m}{V} \text{ kg}$  of water

Latent heat of vaporization =  $33 \times 587 \text{ kcal/m}^3$

$NCV = GCV - \text{Latent heat of vaporization}$

$$\boxed{NCV = GCV - \frac{m}{V} \times 587 \quad \downarrow \text{K cal/m}^3}$$

- (e) During the determination of calorific value of a gaseous fuel by Boy's calorimeter the following result were noted.

Volume of gaseous fuel burnt at NTP =  $0.098 \text{ m}^3$

wt of water heated = 50 kg

wt of steam condensed = 0.051 kg

Temperature of incoming water =  $26.1^\circ\text{C}$

Temperature of outgoing water =  $46.5^\circ\text{C}$

Determine the GCV & NCV of fuel

$$GCV = \frac{W(T_2 - T_1)}{V} \text{ K cal/m}^3$$

$$= \frac{50(46.5 - 26.1)}{0.098}$$

$$= 10408.2 \text{ K cal/m}^3$$

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

$$= 10408.2 - \frac{0.051 \times 587}{0.098}$$

$$= 10102.7 \text{ K cal/m}^3$$

Dulong's formula

Carbon

Hydrogen

Oxygen

Sulphur

$$GCV = \frac{1}{100} [8080 (\% C) + 34500 \left( \% H - \frac{\% O}{8} \right) + 2240 (\% S)] \text{ cal/gm}$$

$$NCV = GCV - 9 H \times 587 \text{ cal/gm}$$

WQ

Calculate the gross & Net calorific value of the following composition.

$$C\% = 80\%$$

$$O = 5\%$$

$$N = 1.4\%$$

$$H = 9\%$$

$$ASH = 2.1\%$$

$$S = 2.5\%$$

$$\text{Q1}) GCV = \frac{1}{100} [8080 \times 80 + 34500 \left( 9 - \frac{5}{8} \right) + 2270 \times 2.5]$$
$$= 8828.025 \text{ K cal/kg}$$

$$NCV = 8828.05 - 9 \times 587 \times \frac{9}{100}$$

~~(a)~~

Calculate GCV & NCV using Dulong's formula

C	O	S	N	Ash	H
80%	5%	2.5%	1.4%	2.1%	rest

~~(b)~~

Concept

$$C + O + S + N + \text{Ash} + H = 100$$

$$H = 100 - C - O - S - N - \text{Ash}$$

$$H = 100 - 80 - 5 - 2.5 - 1.4 - 2.1$$

$$\boxed{H = 9\%}$$

use Dulong formula for numerical

Classification of coal according to ranks

Type of Coal	Percentage of Carbon	Calorific Value
Wood	40 - 45	3500 - 4500
Peat	45 - 60	4125 - 5200
Lignite (Brown coal)	60 - 75	6600 - 7100
Bituminous coal	75 - 90	6600 - 8800
Anthracite	> 90%	> 8400

WZ

Analysis of coal

Proximate analysis.

Ultimate ~~only~~  
analysis

- ① Data varies with the procedure adopted and hence it is called Proximate analysis
- ② It gives information about the quality of coal
- ③ It determine moisture content, volatile matter, ash & fixed carbon content

## A) Proximate Analysis (Type)

- ① Moisture content

1 to 2g of  
Powdered Coal  
sample ( $w$ )       $\xrightarrow[1 \text{ hours}]{105^\circ\text{C} - 110^\circ\text{C}}$       cooled down to  
Room  
Temp ( $w_1$ )

$$\% \text{ Moisture content} = \frac{\text{Loss of wt of coal sample}}{\text{Initial wt of coal sample}} \times 100$$

$$= \frac{(w - w_1)}{w} \times 100$$

Date \_\_\_\_\_

② Volatile Matter  
 Moisture free sample (1g of carbon) (High % is undesirable)

$950 \pm 20^{\circ}\text{C}$  → Cooled down & stare  
 7 min ( $w_2$ ) weight

$$\begin{aligned} \% \text{ of volatile Matter} &= \frac{\text{Loss of w wt of sample}}{\text{initial wt of coal}} \\ &= \left( \frac{w_2 - w_1}{w} \right) \times 100 \end{aligned}$$

③ Ash content / Non combustible Content

Moisture Content & volatile matter free Sample  $\xrightarrow[1/2 \text{ hr}]{750 \pm 20^{\circ}\text{C}}$  wt of residue ( $w_3$ )

$$\begin{aligned} \% \text{ Ash content} &= \frac{\text{wt of residue}}{\text{initial weight of coal}} \times 100 \\ &= \frac{w_3}{w} \times 100 \end{aligned}$$

④ fixed carbon

$$\text{fixed C} = 100 - [\% \text{ Moisture content} + \% \text{ of volatile Matter} + \% \text{ of Ash content}]$$

% fixed Carbon ↑ = Good Quality Coal ↑

Significance of proximate analysis

- ① % fixed carbon ↑ Higher than calorific value
- ② Fixed carbon acts as a main heat generator during burning
- ③ High volatile matter content indicates easy ignition of fuel.

NumericalApproximate analysis

(Q1) 2.0 gm of coal sample was heated in a Silica crucible for 1 hour at  $110^{\circ}\text{C}$ . The residue was cooled down to room temp & its weight was 1.975 gram. Then it is covered with a ~~vented~~ vented lid & strongly heated for exactly 7 mins at  $950 \pm 20^{\circ}\text{C}$ . The residue weight was 1.328 gm. Then the residue was heated without cover till a constant weight was obtained. The residue weight was 0.204 gm. Calculate the % of Moisture content, volatile Matter, Ash content & Fixed C.

Sol Initial wt of coal sample ( $w$ ) = 2 gm  
wt of coal sample after heating ( $w_1$ )  
at  $110^{\circ}\text{C}$  = 1.975 gm

wt of coal sample after heating at ( $w_2$ )  
 $950 \pm 20^{\circ}\text{C}$  = 1.328 gm

wt of residue left ( $w_3$ ) = 0.204 gm

% moisture content = ~~2.00~~

$$\frac{2 - 1.975}{2} \times 100$$

% volatile matter =  $\frac{1.975 - 1.328}{2} \times 100$

% ash content =  $\frac{0.204}{2} \times 100$

% fixed C =  $100 - [ \% \text{ MC} + \% \text{ VM} + \% \text{ Ash content} ]$

## Ultimate analysis (Elemental analysis)

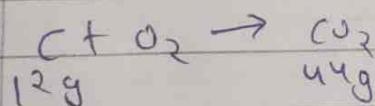
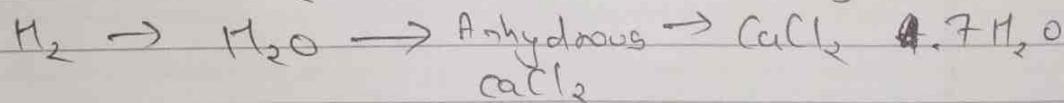
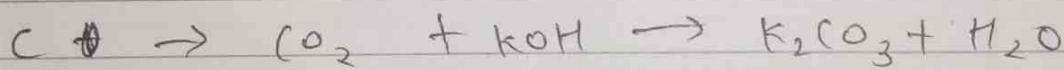
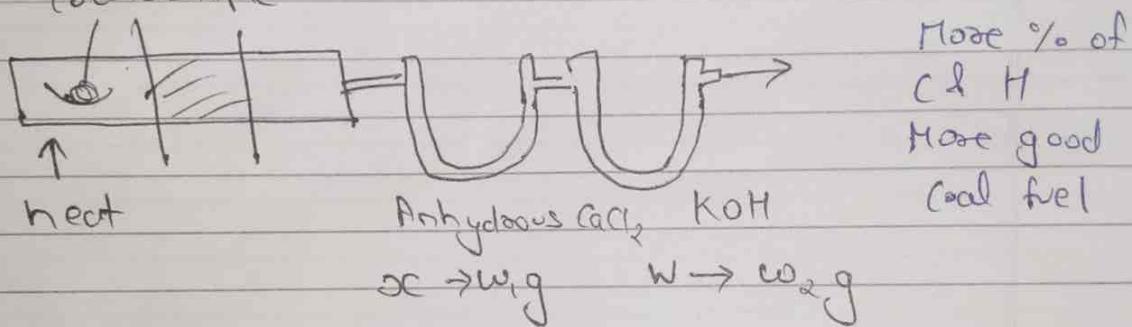
It is useful for combustion calculation.

Ultimate analysis also known as elemental analysis. It is method used to determine the carbon, hydrogen, nitrogen, sulphur and oxygen content present in solid fuel.

## Ultimate analysis (C, H, N, O, S)

① % of C & H  
coal sample

Combustion gives both carbon, water and heat during combustion of coal



$$\% \text{ of C} = \frac{12}{44} \times \frac{\text{Increased wt of KOH tube due to absorption of } \text{CO}_2}{\text{Initial wt of coal taken}} \times 100$$

$$\% \text{ of H} = \frac{2}{18} \times \frac{\text{Increased wt of } \text{CaCl}_2 \text{ tube due to absorption of } \text{H}_2\text{O}}{\text{Initial wt of coal taken}} \times 100$$

(2) Determination of N

$$\% \text{ of N} = \frac{1.4 \times N_1 V_1}{\text{wt of coal sample}}$$

$V_1$  = Volume of used acid for neutralization  
 $N_1$  = Normality of acid

(Q) 1.56g of coal sample was Kjobhalized and  $\text{NH}_3$  gas thus released, was absorbed in 50ml of 0.1N  $\text{H}_2\text{SO}_4$ . After absorption the excess acid required 6.25ml of 0.1N of NaOH for exact Neutralization, calculate the % of N.

Sol)

$$\% \text{ of N} = \frac{1.4 \times N_1 V_1}{\text{wt of coal sample}}$$

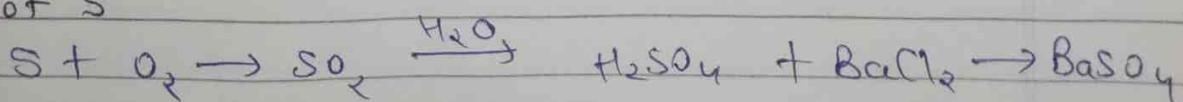
$$\Rightarrow \text{wt of coal sample} = 1.56\text{g}$$

$$\begin{aligned} \Rightarrow \text{Volume of acid used for} \\ \text{neutralization of } \text{NH}_3 &= (50 - 6.25)\text{ml} \\ &= 43.75\text{ml} \end{aligned}$$

$$\text{Normality of acid} = 0.1\text{N}$$

$$\% \text{ of N} = \frac{1.4 \times 43.75 \times 0.1}{1.56}$$

(3) % of S



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

2g of coal sample in a quantitative analysis gives 0.175gm of BaSO<sub>4</sub>. Calculate % of S

(Q1)

$$\% \text{ of S} = \frac{32}{233} \times \frac{0.175}{0.02} \times 100$$

(Q2)

% of ash

$$\frac{\text{weight of ash left}}{\text{weight of coal taken}} \times 100$$

(Q3)

% of Oxygen (O)

$$\% \text{ of O} = 100 - \% [C + H + N + S + \text{Ash}]$$

(Q4)

1g of sample of coal was used in a bomb calorimeter for the determination of calorific value. Calorific value of coal was found to be 8800 cal/g. The ash formed in the bomb calorimeter was extracted with acid and the acid extract was heated with barium nitrate solution and a precipitate of Barium sulphate was obtained. The precipitate was filtered, dried and weighed. The weight of precipitate was found to be 0.08g. Calculate the % of sulphur in the coal sample.

(Q5)

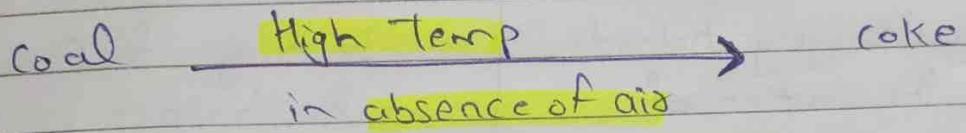
$$\% \text{ of S} = \frac{\text{wt of BaSO}_4 \text{ ppt obtained}}{233 \times \text{wt of coal sample taken}} \times 32 \times 100$$

$$= \frac{0.08}{233 \times 1} \times 32 \times 100$$

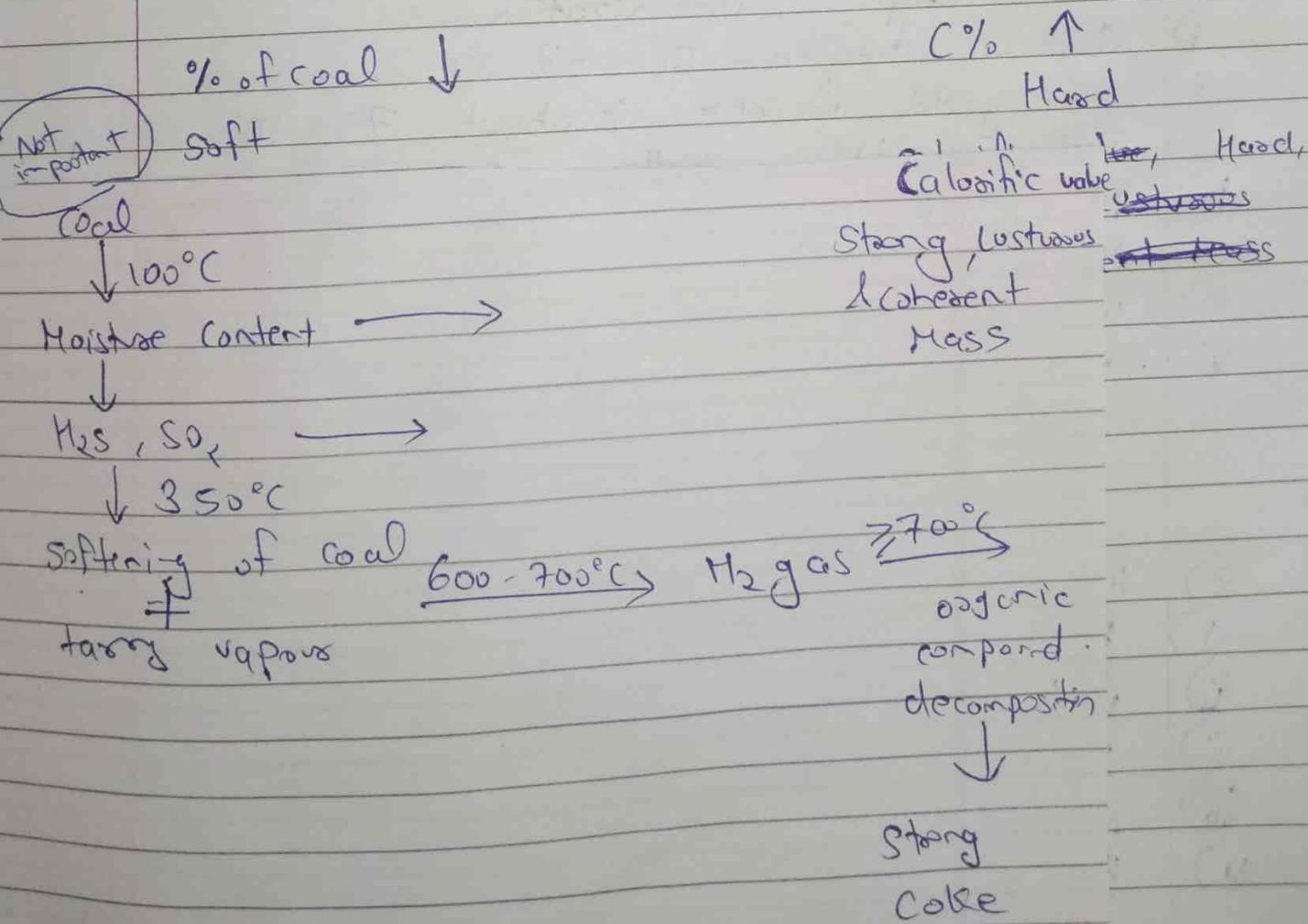
$$\Rightarrow \frac{0.08 \times 32 \times 100}{233 \times 1} = 1.098\%$$

## Carbonization Process (Destructive distillation)

The process of converting coal into coke is called carbonization.



The decomposition of coal by heating it in the absence of air to give a solid residue, coke is called carbonization.



- 1) Coal does not possess as much strength and **porosity** as coke
- 2) Coke burns with short flame, ~~coal~~  
Coal burns with a long flame
- 3) By coking, **undesirable sulphur** is removed
- (4) ~~W.L.~~ Coke but not coal is used as fuel for Metallurgical Processes



### Coal

- i) Calorific value is less
- ii) Mechanical strength of coal is less
- iii) Coal is formed by decaying materials by the action of heat and pressure

### Coke

- i) Calorific value is high
- ii) Mechanical strength of coke is higher
- iii) Coke is formed by heating of coal in absence of air

### Type of carbonization

- i) Low temp carbonization
- ii) Coal is heated  $500 - 700^{\circ}\text{C}$
- iii) The yield of coke is about  $75 - 80\%$
- iv) ~~Volatile Matter~~ volatile Matter ( $5 - 15\%$ )
- v) Mechanical strength  $\rightarrow$  low
- vi) Nature  $\rightarrow$  Soft
- vii) Use  $\rightarrow$  Domestic purpose  
Bye products gas produced has a calorific value of  $6500 - 9500 \text{ kcal/m}^3$

### 3) High temperature carbonization

- i) High temp ( $900 - 1200^{\circ}\text{C}$ )
- ii) Yield of coke ( $65 - 75\%$ ) ~~more~~
- iii) Volatile Matter ( $1 - 3\%$ )
- iv) Nature  $\rightarrow$  Hard
- v) Use  $\rightarrow$  Industrial

vi) Mechanical Strength  $\rightarrow$  High

vii) By product gas produced has a calorific value of about  $5400 - 6000 \text{ Kcal/m}^3$

~~vn~~ Manufacture of coke

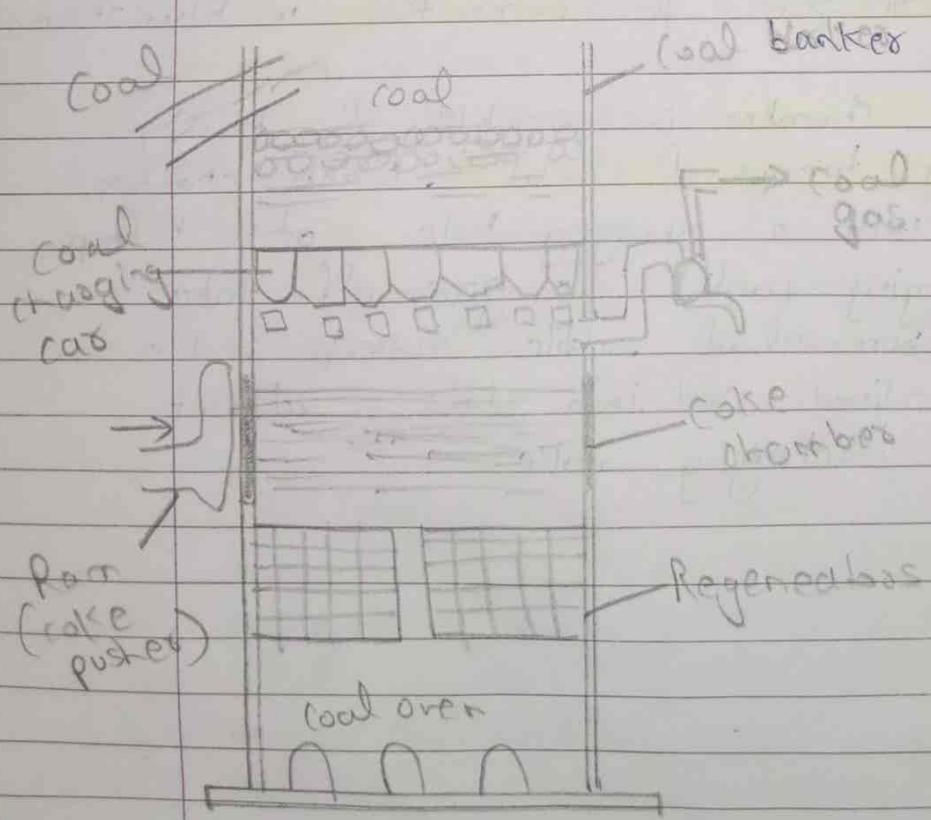
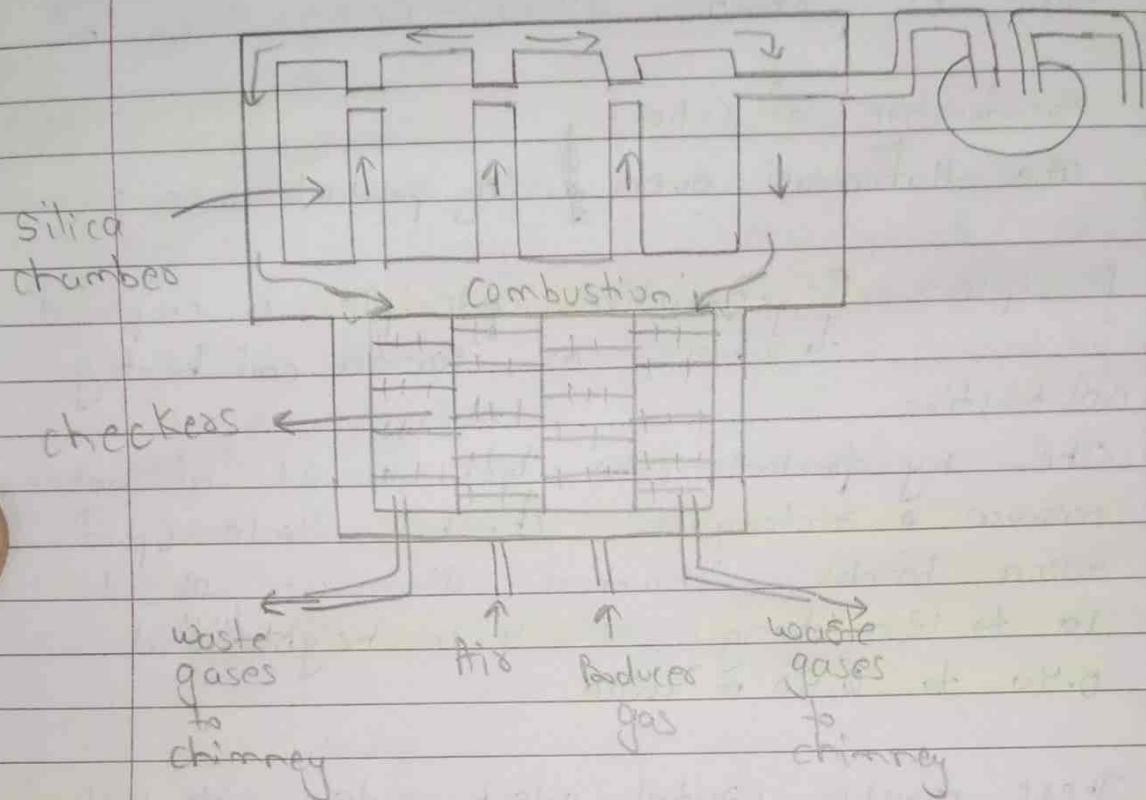
otto - Hoffmann oven  By product oven process

Principle  $\rightarrow$  Regenerative principle is employed to achieve an economical heating construction

The by product coke oven consist of number of narrow rectangular chamber made up of silica bricks, chambers dimension about 10 to 12 m long, 3 to 4 m height and 0.40 to 0.50 m wide.

These chambers erected side by side with vertical flues or interspace for combustion in b/w them.

One single chamber is capable of holding 16 to 24 tonnes of coal. Each chamber is provided with a charging hole at the top (for charging coal), a gas off-take (for the removal of volatile matter) and a refractory-lined cast iron door at each ends for discharging coke.



## Working

coal is enter with the ~~coal charging~~ <sup>help of</sup> bunker coal charging door then it with the help of coal car it enters into the ~~bunker~~ <sup>coal basket</sup> then the chambers are closed tightly at both end to prevent any access of air. Then the produced gas are produced in it at the bottom of the container and the temperature is  $1200^{\circ}\text{C}$  then due to the high temperature the coal burns and combustion takes places. Due to the combustion some amount of gases are waste which has been trap from the waste gases to chimney. In this the waste gases are coming they again heat the checker and through which the waste gas is in ~~use~~ of our use and the thermal efficiency, net efficiency increases. Then hot coke is taken and the quenching process takes places. (Quenching process  $\rightarrow$  rapid cooling or make the material temperature room temperature).

Quenching are done by two ways

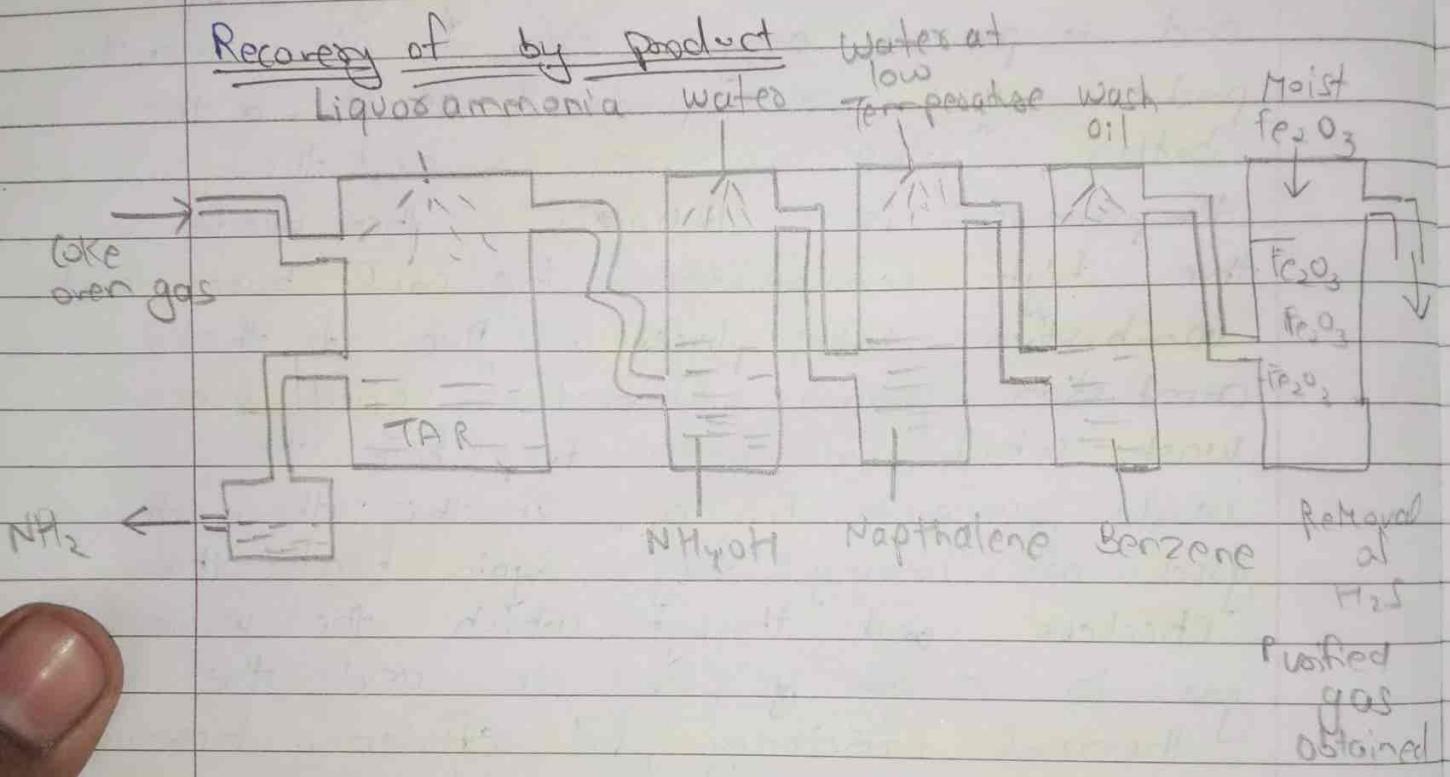
a) wet quenching  $\rightarrow$  hot coke  $\oplus$  water  
 $\xrightarrow{\text{Storage tank}}$

b) dry quenching  $\rightarrow$  hot coke  $\oplus$  air  $\oplus$  inert gas  
 $\xrightarrow{\text{Storage tank}}$   $\oplus$  cool distillation

In dry off quenching efficiency is more.

~~Ques~~ why dry quenching is more useful than wet quenching

Dry coke produced during dry quenching is more strong, dense, graphitized, non-reactive, cheaper, contain lesser dust than wet quenched coke



The gas coming out from the oven is known as coke oven gas (waste gas)

Recovery of tar → The gas is first passed through a tower in which liquor ammonia is sprayed. Here dust and tar get collected at a tank below, which is heated by steam coil to recover back ammonia sprayed. The ammonia is used again.

Recovery of ammonia The gases from the chambers are then passed through a tower in which water is sprayed. Here ammonia reacts with water to give  ~~$\text{NH}_4\text{OH}$~~   $\text{NH}_4\text{OH}$ . Recovery of  $\text{NH}_4\text{OH}$  is important because it blocks all the pipe.

Recovery of Naphthalene The gases are then passed through cooling towers in which water at very low temperature is sprayed & naphthalene gets recovered.

Recovery of benzol The gases are then sprayed with petroleum and benzene gets recovered.

Recovery of  $\text{H}_2\text{S}$  The gases are then passed into the chambers where moist  $\text{Fe}_2\text{O}_3$  are sprayed and moist  $\text{Fe}_2\text{O}_3$  react with gases and sulphur content,  $\text{H}_2\text{S}$  are removed. Important (sulphur may form oxide  $\text{SO}_2$  and  $\text{H}_2\text{S}$  from  $\text{H}_2\text{SO}_4$  due to this they corrode all the other thing) after this pure gas are recovered.

Purified gas is coal gas or coke oven gas  
Coal gas is used as domestic fuel  
Main component of coal gas are  
 $\text{CH}_4$ ,  $\text{H}_2$  with small amount of  $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{N}_2$

The process of heating coal in the absence of air is known as destructive distillation of coal. coke, coal tar, coal gas are the byproduct obtained during the destructive distillation of coal.

Coking coal → If the residue (coke) obtained after heating is hard, strong, usable for metallurgical purpose, the original coal is known as coking coal.

### coking coals

Some of the organic component of coal have fusion properties when heated. The ability of coal to melt on heating and to form a coherent residue on cooling called Coking coals.

### characteristics of Metallurgical coke

Most important industrial fuel is metallurgical coke. characteristics

- ① calorific value High
- ② combustibility easy
- ③ cost cheap
- ④ porosity High
- ⑤ strength Hard & Strong

### Liquid fuel

use for Domestic as well as industrial fuel

Better, More efficiency

Petrol

Petroleum → Petrol → Gasoline  
oleum → oil

C → ~~80~~ 80 - 87 %

H → 11 - 15 %

S → 0.1 - 3.5 %

O → 0.1 - 0.9 %

N → 0.1 - 4.9 %

Refining

Process in which petroleum is separated into different fractions having different boiling point is called refining of petroleum

- Step 1 → Separation of water or Cottrell's process
- Step 2 → Removal of Sulphur compounds
- Step 3 → Fractional distillation

### Refining of Gasoline

Unsaturated compound



Gum formation

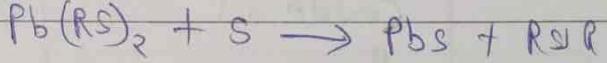
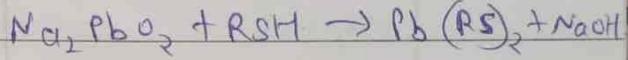


Treatment with soil  
 $H_2SO_4$

Sulphur compound  
Removal of sulphur



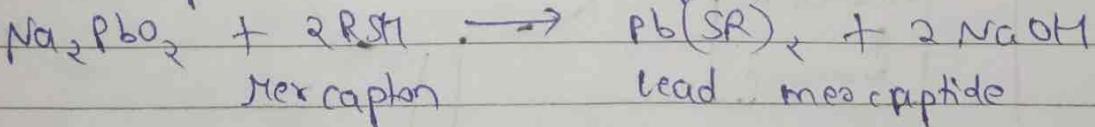
Sweetening of petrol



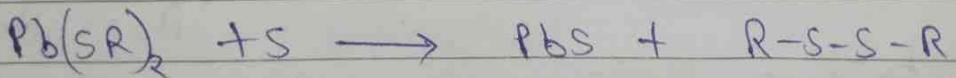
Mercaptan      ↓  
                    Dissolved compound

Fraction obtain b/w  $40^\circ C$  to  $120^\circ C$  called petrol / gasoline  
Sulphur compound (Removal of Sulphur)

① gasoline is passed over sodium plumbite



② Lower Molecular weight Mercaptides  $\rightarrow$  Insoluble in petrol  
Higher      "      "      "      "  $\rightarrow$  Soluble in petrol



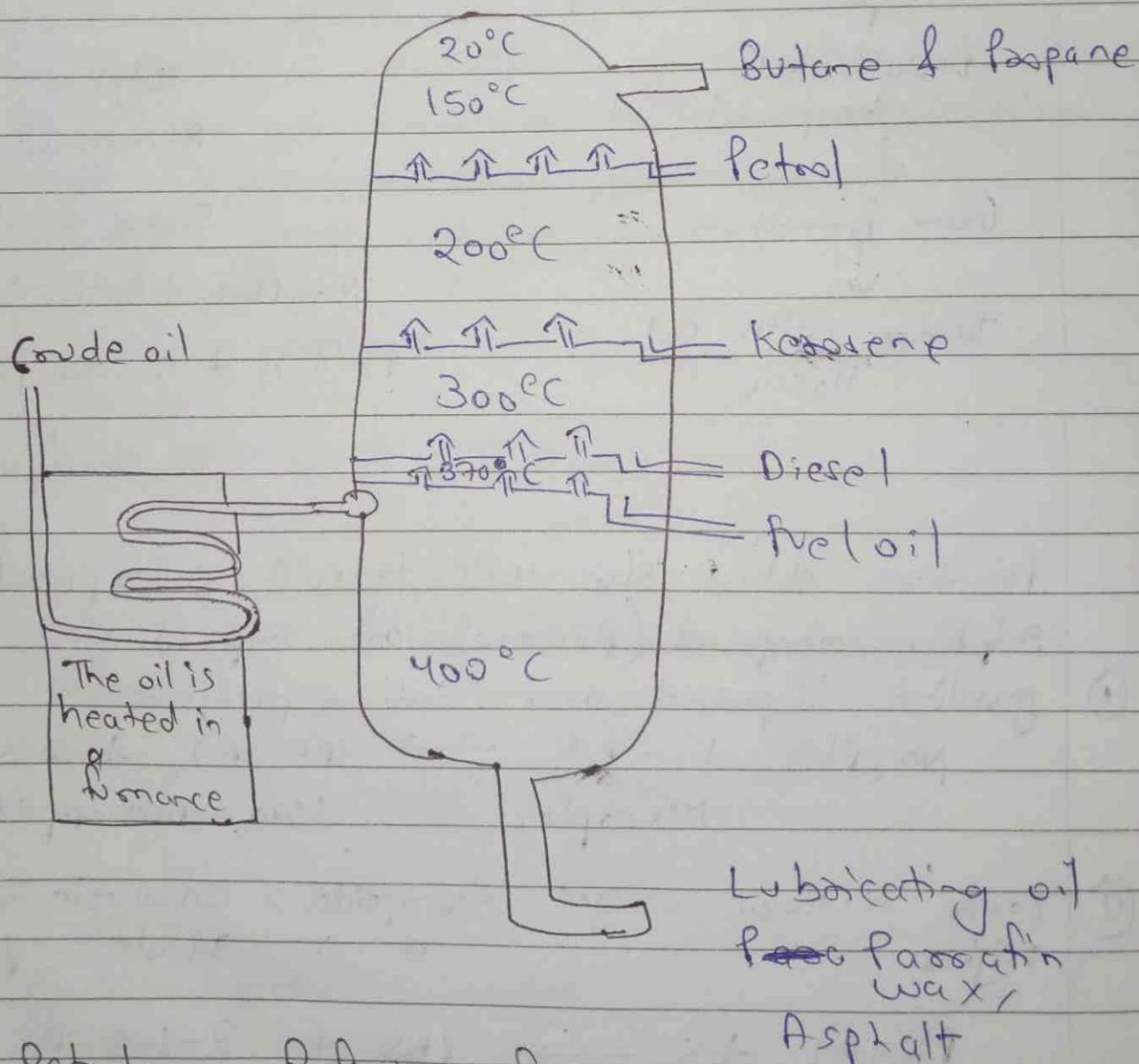
Insoluble Mercaptide  $\rightarrow$  bad odour converted  $\rightarrow$  disulphide  
which are soluble in petrol & do not have bad odour  
but still its presence is undesirable

- ③ gasoline is further refined by vapour phase treatment
- ④ gasoline free from this compound

5) Stabilization  $\rightarrow$  gasoline obtained may contain some dissolved gases like Methane, ethane, etc.

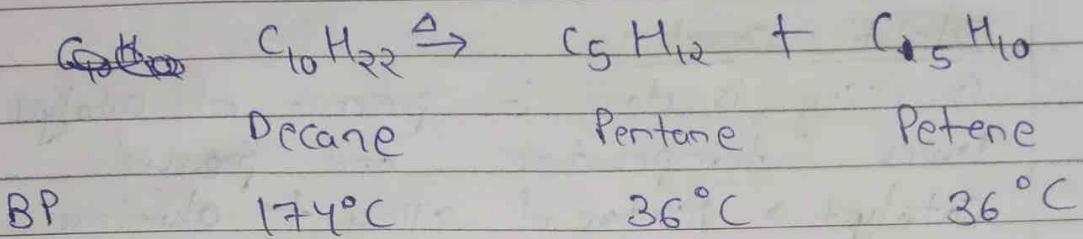
These gases are removed by process stabilization. Some inhibitors are added to gasoline to improve its storage quality of gasoline.

6) Then it is mixed with various Anti-knocking agents to satisfy its octane no. of petrol.



Petroleum Refining, formation

Cracking → It is defined as the decomposition of high molecular weight compound having high boiling point into simpler or low molecular weight compound having low boiling point by application of heat with or without catalyst.



### Cracking

Theoretical  
Cracking takes place in presence  
of heat and pressure

Liquid  
phase

- \* Charge in liquid form
- \* Pressure 100 kg/cm<sup>2</sup>
- \* Temperature 475 - 530°C
- \* Cracked product separated by fractionating column
- \* Any oil

Vapour  
phase

- only those oil which can vaporize at low temperature can be cracked
- \* Temperature 670 - 720°C

Fixed bed  
Catalytic  
Cracking

Moving  
bed  
catalytic  
cracking

### Catalytic

#### Characteristics

Cracking Temperature

Pressure

Octane rating of petrol

Type of oil

Time required for cracking

Liquid phase

475 - 530°C

100 kg/cm<sup>2</sup>

65 - 70

Any oil

More

Vapour phase

620 - 720°C

10 - 20 kg/cm<sup>2</sup>

> 70

oil should vaporized less

Mechanism of thermal cracking  
 Thermal cracking is follow by free radical Mechanism

- ① Initiation
- ② Propagation
- ③ Termination

### Catalytic cracking

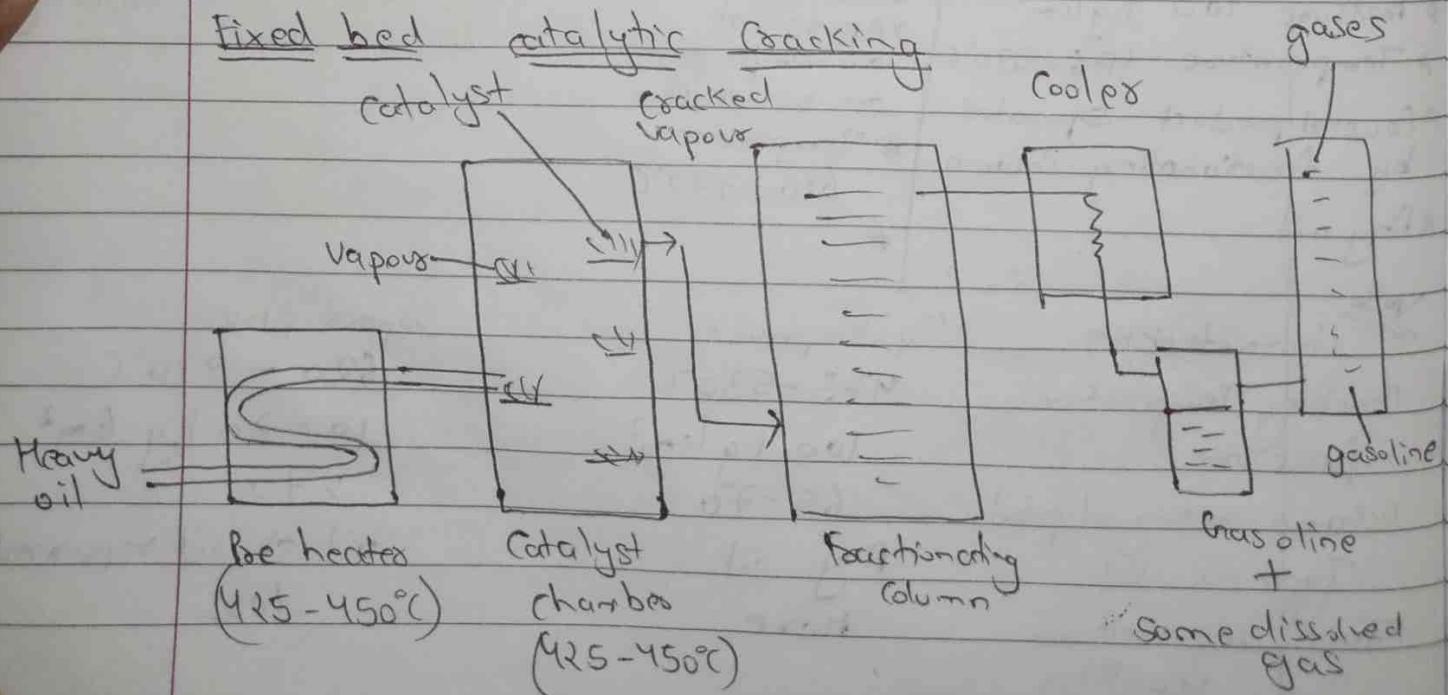
Cracking is done in presence of catalyst at lower temperature and pressure

Catalyst  $\rightarrow$  mixture of silica + alumina

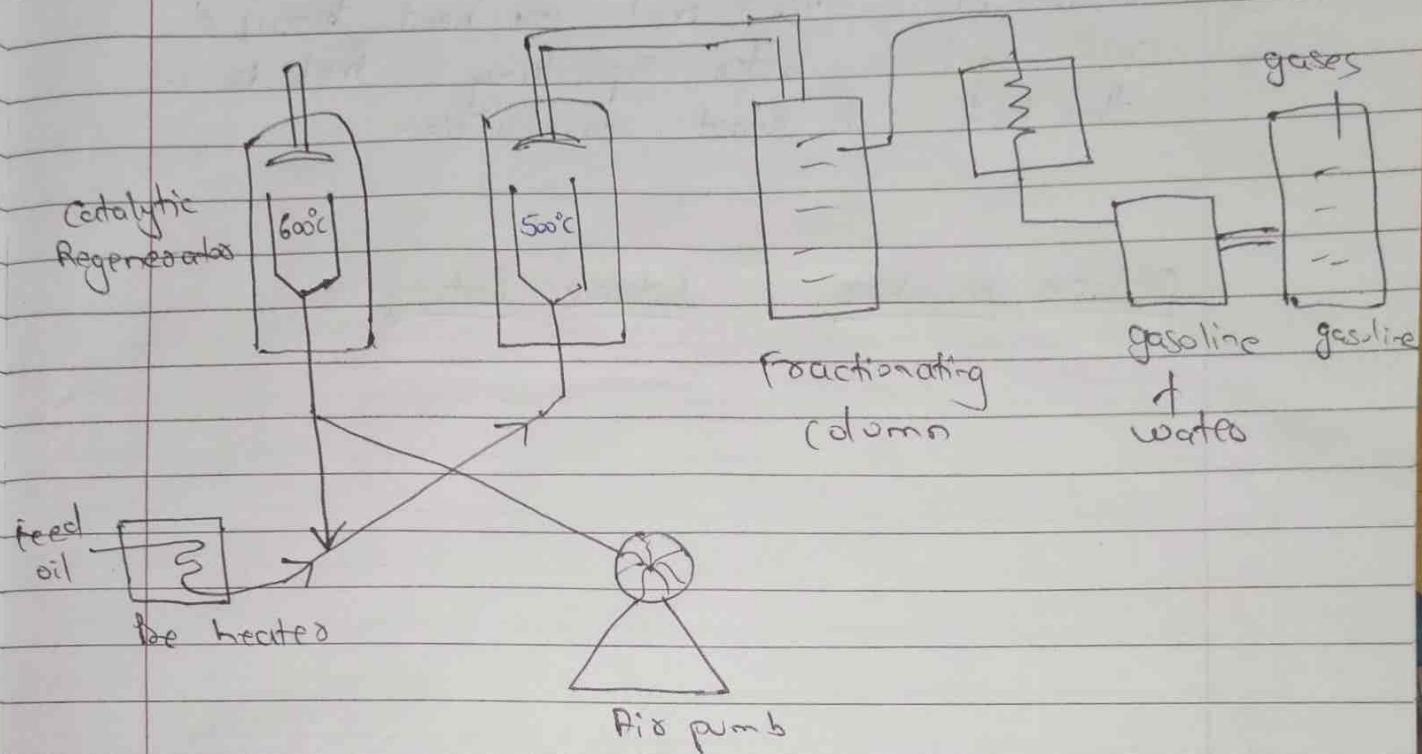


Advantages catalytic cracking over thermal cracking

- a) High temperature & pressure are not required in the presence of a catalyst
- b) Yield of gasoline is higher about 70% of raw material is converted into gasoline.
- c) Coke forming material are absorbed by the catalysts.



## Moving bed catalytic cracking



### Knocking

It is the sharp metallic sound similar to rattling of hammer which is produced in the internal combustion engine due to immature ignition of air / fuel mixture

\* Knocking  $\uparrow$  = length of hydrocarbon  $\uparrow$

n heptane  $>$  n hexane  $>$  n pentane

\* Knocking  $\downarrow$  =  $\uparrow$  compactness of Molecule,  
double bond, cyclic structure

\* Knocking  $\downarrow$  =  $\uparrow$  branched chain isomers

n heptane  $>$  2 methyl hexane  $>$  2,2 dimethyl Pentane

### Cause of Knocking

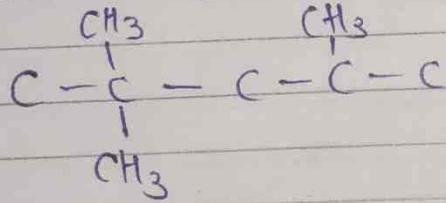
- 1) Pre ignition  $\rightarrow$  Before Sparking  $\rightarrow$  compression of air fuel at heat front  $\rightarrow$  fuel is in time
- 2) Self ignition after Sparking fuel is in the box is start combustion

### Octane Number

### Octane Rating

Octane Number  $\rightarrow$  It is define as the % of iso octane in the mixture of iso octane & n-heptane which has the similar  $\Rightarrow$  knocking characteristics to that of the fuel under study under sense set of ~~the~~ condition

- ① It is used in Petrol engine, gasoline
- Iso octane (2,2,4 trimethyl pentane)



- ③ Additive

- ① Benzene

- ② Tetraethyl lead

- ③ 1,2 dibromo ethane

- ④

Saturated Hydrocarbon (Max)

$\downarrow$   
Branched chain Hydrocarbon

$\downarrow$   
Olefin

$\downarrow$   
Cyclic hydrocarbon

$\downarrow$   
Aromatics (Min)

$\rightarrow$  Knocking decrease as we move down the group

$\rightarrow$  Anti knock property increase as we move down the group

$\rightarrow$  Octane number of fuel increase as we move downward

Saturated Hydrocarbon > Branched chain Hydrocarbon  
(Maximum)

define > Cyclic hydrocarbon

> Aromatics (Minimum)

⑤ Straight chain Hydrocarbon

Molecule are low octane numbers

Cetane Rating or Cetane Number

Cetane No → It is the define as the % of hexadecane  
in the mixture of hexadecane &  
& 1 Methyl Naphthalene which has the  
similar knocking characteristics.  
& that of the fuel under study under  
same set of condition.

\* It is used in Diesel engine

\* Aromatics > Branched chain > olefine > Naphthalenes  
(Maximum) Hydrocarbon  
> alkane  
(least)

→  
Anti Knocking

Additives

① ethyl Nitrate  
② Iso propyl Nitrate

⑤ straight chain  
Hydrocarbon Molecule  
are best, have  
high cetane  
Number

Ignition delay → The combustion of fuel in a  
diesel engine is not spontaneous the  
interval b/w the start of fuel injection  
and its ignition is called ignition  
delay.

- Q) Differentiate b/w octane No & cetane No  
A) straight chain hydrocarbon is a good diesel engine but a bad petrol engine.

## Gaseous fuel

Gaseous fuel obtained

- ① Nature
- ② from Solid fuel (produces gas, water gas)
- ③ from petroleum

### Gaseous fuel

- 1) Natural gas
- 2) CNG
- 3) LPG
- 4) Coal gas
- 5) Producer gas
- 6) Water gas
- 7) Oil gas

#### Natural gas

Composition → 70 - 90 % of Methane  
5 - 10 %. ethane  
3 %. Hydrogen

#### uses

- a) Domestic fuel
- b) Used in the preparation of compressed Natural gas
- c) Due to less pollution it is a good substitute of petrol & diesel
- d) used for manufacture of synthetic chemicals

3) CNG (Compressed natural gas)

Zero pollution

Clean fuel

Environment friendly fuel

3) LPG

Composition → Butane, iso-butane, propane

Mixture of gases

uses

a) ~~Health~~ Not polluted the air

b) LPG stoves quickly supply heat and work

4) Coal gas

C (in absence of air) → coke + coal gas

composition →  $H_2$ ,  $CH_4$ ,  $CO$ ,  $C_2H_2$ ,  $C_2H_4$ ,  $N_2$ ,  $CO_2$

uses

i) Raw Material for ammonia production

ii) Used as a source of light

iii) In Metallurgical operations to providing a reducing atmosphere

5) Producer gas

composition →  $CO + N_2$

uses

Manufacture of steel, glass

As a reducing agent in Metallurgical operation

6) Water gas (Blue gas)

composition →  $CO + H_2$

uses

used for production of Hydrogen

water gas is used as a fuel in furnace

2) Oil gas  
 $\text{CH}_4$ ,  $\text{H}_2$ ,  $\text{CO}$ ,  $\text{CO}_2$

uses

used as laboratory gas

used to improve the calorific value of water

Q) Calculate the Minimum amount of air required for the complete combustion of 100kg of fuel containing C = 80%.

H = 6%, O = 5%. S = 2% all rest N

Calculate the % of dry product of combustion if 25% excess of air is supplied.

Sol)

Step 1

Amount of fuel = 100 kg

Step 2

comp	weight	chemical react	$\text{O}_2$	dry product
C	80	$\text{C} + \text{O}_2 \rightarrow \text{CO}_2$ $\frac{12}{32} \times 80$	$\frac{32}{12} \times 80$	
H	6	$2\text{H} + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}$	$\frac{16}{32} \times 6$	
O	5			
S	2	$\text{S} + \text{O}_2 \rightarrow \text{SO}_2$	$\frac{32}{32} \times 2$	
N	7			

$$\begin{aligned}
 \text{Total } \text{O}_2 \text{ required} &= \frac{32}{12} \times 80 + \frac{16}{32} \times 6 + \frac{32}{32} \times 2 \\
 &= 213.3 + 50 \\
 &= 263.3
 \end{aligned}$$

we will Minus O<sub>2</sub> given

$$263.6 - 5 = 258.3 \text{ Kg}$$

$$\text{Air required} = \frac{258.3}{23} \times 100 \\ = 1123.04 \text{ Kg}$$

b) Excess air wala =  $1123.04 \times \frac{125}{100}$   
= 1403.8 Kg

Dry product composition  
 $\frac{12}{12} \text{ kg of C} \rightarrow \frac{44}{80} \text{ kg of CO}_2$   
 $\frac{80}{12} \text{ kg of C} \rightarrow \left(\frac{44}{12} \times \frac{80}{80}\right) \text{ kg of CO}_2$   
Amount of O<sub>2</sub> → according to  $\frac{44}{12} \times 60$

Amount of SO<sub>2</sub> →  $\frac{64}{32} \times 2 \text{ Kg}$

Amount of O<sub>2</sub> =  $\frac{23}{100} \times 280.79 \quad (\text{excess wala})$

Amount of N<sub>2</sub> =  $\left[ \frac{77}{100} (1403.8) + 7 \right] \text{ Kg}$   
=

Total dry product

$$\Rightarrow \frac{44}{12} \times 60 + \frac{64}{32} \times 2 + \frac{23}{100} \times 280.7 + \frac{77}{100} \times 1403.8 + 7 \\ = 1449.79 \text{ Kg}$$

$$\% \text{ CO}_2 = \frac{\text{Amount of CO}_2}{\text{Total wt of dry product}} \times 100$$

% SO<sub>2</sub>

Similarly

% O<sub>2</sub>

% N<sub>2</sub>

- (Q3) A gaseous fuel of 1 m<sup>3</sup> has the following composition by volume

CH<sub>4</sub> = 4%

CO = 26%

H<sub>2</sub> = 10%

N<sub>2</sub> = 50%

If 20% excess air is supplied calculate the actual volume of air supplied.

21%  $\rightarrow$  O<sub>2</sub> (for volume)  
 79%  $\rightarrow$  N<sub>2</sub>

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(a) Amount of fuel = 1 m<sup>3</sup>

Components	Amount	Chemical reaction	Amount of O <sub>2</sub> required (m <sup>3</sup> )
CH <sub>4</sub>	$\frac{4}{100} \times 1 = 0.04 \text{ m}^3$	CH <sub>4</sub> + 2O <sub>2</sub> $\rightarrow$ CO <sub>2</sub> + 2H <sub>2</sub> O	0.04 × 2 =
CO	$\frac{26}{100} \times 1 = 0.26 \text{ m}^3$	CO + $\frac{1}{2}$ O <sub>2</sub> $\rightarrow$ CO <sub>2</sub>	0.26 × $\frac{1}{2}$
H <sub>2</sub>	0.1 m <sup>3</sup>	H <sub>2</sub> + $\frac{1}{2}$ O <sub>2</sub> $\rightarrow$ H <sub>2</sub> O	0.1 × $\frac{1}{2}$
N <sub>2</sub>	0.5 m <sup>3</sup>		

$$\begin{aligned}\text{Minimum O}_2 \text{ required} &= 0.04 \times 2 + 0.13 + 0.05 \\ &= 0.26 \text{ m}^3\end{aligned}$$

$$\text{Minimum air required} = \frac{100}{21} \times 0.26 = 1.23 \text{ m}^3$$

$$\text{Excess air} = \frac{20}{100} \times 1.23 \text{ m}^3$$

$$\begin{aligned}\text{Actual air Supplied} &= 1.23 + 0.24 \\ &= 1.47 \text{ m}^3\end{aligned}$$