Fuel
&
Combustion

Fuel

- Fuel is any material which is capable of releasing energy when it's chemical or physical structure is altered.
- Fuel releases its energy either through chemical means such as combustion or nuclear means such as nuclear fission or nuclear fusion.
- Fuel + Oxygen $\longrightarrow$ Product +Energy
- An important property of a useful fuel is that its energy can be stored to be released only when needed and that the release is controlled in such a way that the energy can be harnessed to produce work.

CLASSIFICATION OF FUELS

- On the basis of their **occurrence**, fuels may be divided into:
- **Primary or Naturally Occurring Fuels**. Eg. Wood,Crude oil,Natural gas
- **Secondary or Artificial Fuels** derived from primary Fuels.Eg. Coke,Diesel, Biogas
- On the basis of **state** of aggregation, fuels are classified as follows:
- **Solid fuel** eg. Wood, Coal, Coke
- **Liquid fuel** eg. Crude oil, Diesel, Petrol, Kerosene
- **Gaseous fuel** eg. Natural gas, Bio gas, Water gas, Coal gas, Producer gas

Comparison of Fuel

S. No.	Property	Solid Fuel	Liquid	Gaseous
1.	Calorific value	Low	Higher	Highest
2.	Specific gravity	Highest	Medium	Lowest
3.	Ignition point	High	Low	Lowest
4.	Efficiency (thermal)	Poor	Good	Better than liquid fuel
5.(a) (b) (c)	Air required for Combustion Combustion rate Combustion control	Large and excess of air Slow process Not easy	Less excess of air Quick Controllable	Slight excess of air Very rapid and efficient Under control
6.	Risk of fire hazards	Least	Greater	Very high
7.	Use in I.C engine	Cannot be used	Already in use	Can be used
8.	Mode of supply	Cannot be piped	Can be piped	Can be piped
9.	Relative cost	Cheaper	Costly	More costly than solid & liquid fuel
10.(a) (b) (c)	Special storage Storage Care in storage and transport	Large Easy Less care required	Less than liquid fuel Close container Care is necessary	Very high space Leak proof storage tanks and great care. Great care required
11.	Smoke	Depends upon quality of fuel	Generally smoke contains high carbon content & aromatic compound	No smoke production
12.	Ash	Production of ash depends on quality of fuel	No production of ash	No production of ash

Characteristics of a good fuel:

- High calorific value
- Low moisture content
- Moderated ignition temperature
- Size of fuel (for solid fuel)
- High calorific intensity
- Low non combustible matter content
- Efficiency
- Low storage cost
- Low cost
- Easy to transport

CALORIFIC VALUE

- The calorific value of a substance, usually a fuel or food is the amount of heat released during the combustion of a specified amount of it.
- **Units of Calorific Value:** Calorific values of solid and liquid fuels are usually expressed in Calories per gram (cals/g) or Kilocalories per kilogram (Kcals/Kg) or British Thermal Units per pound (B.Th.U./lb),
- whereas the calorific values of gases are expressed as Kilocalories per cubic metre (Kcals/m^3) or British thermal units per cubic foot (B.Th.U./ft^3) or C.H.U./Ib or C.H.U./ft^3.

Interconversion of units

- These units can be inter-converted as follows:

- 1 cal/g = 1 Kcal/Kg = 1.8 B.Th.U./Ib
-
- 1 Kcal/m^3 = 0.1077 B.Th.U./ft^3
-
- 1 B. Th.U./ft^3 = 9.3 Kcals/m^3

Types of Calorific Value

- **Gross and Net Calorific value (GCV and NCV)**

- It is defined as the total quantity of heat liberated when a unit mass of fuel is burnt completely in the presence of oxygen. The quantity of liberated heat is known as higher calorific value or **gross calorific value**. It is determined by bringing all the products of combustion back to the original pre-combustion temperature and vapour produced are not allowed to escape.

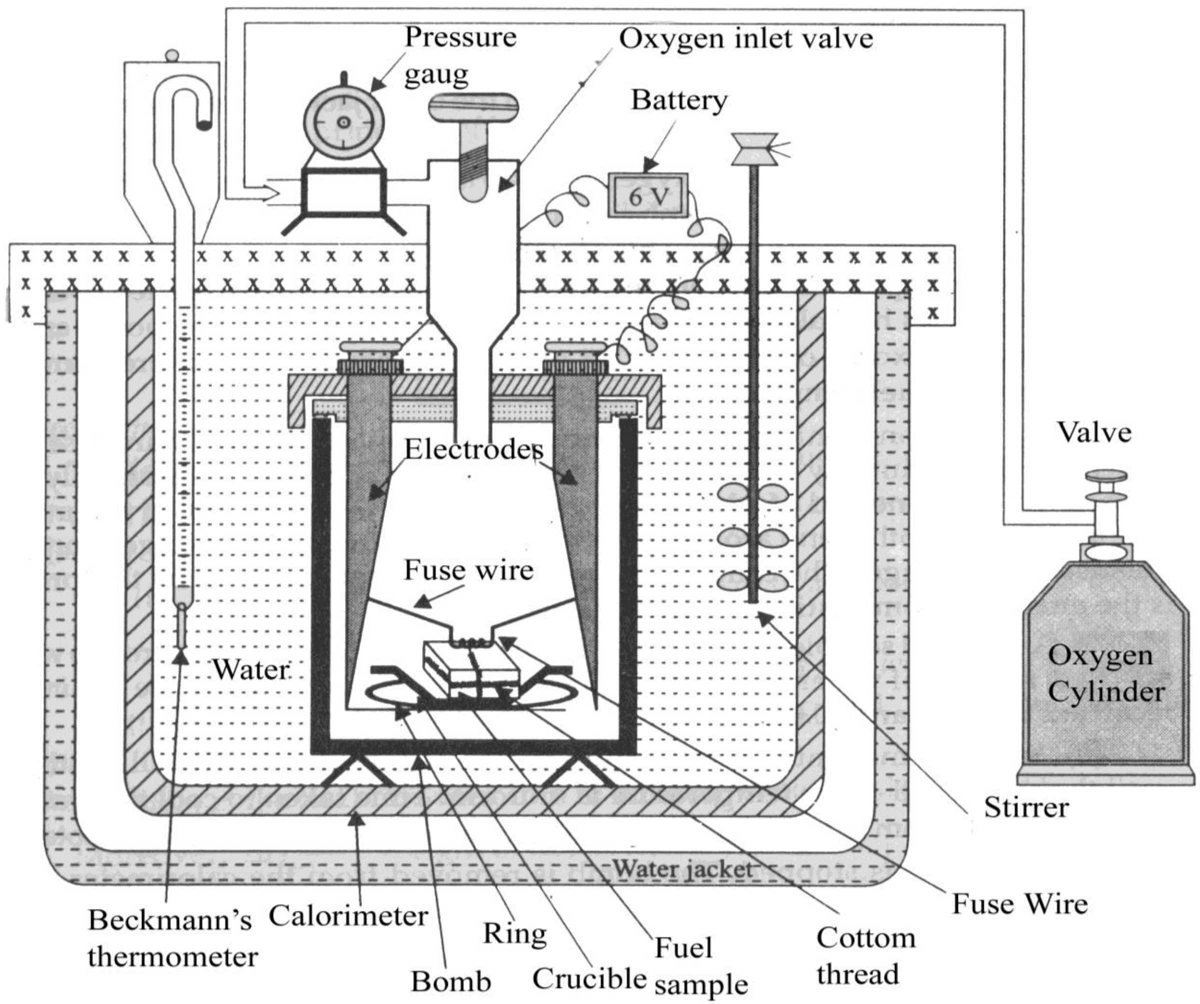
- Lower calorific value or net calorific value is determined by subtracting the heat of vaporization of the water produced by combustion from the higher calorific value. It is defined as the total quantity of heat liberated latest heat of steam when a unit mass of fuel is burnt completely in the presence of oxygen and the products formed are allowed to escape in the atmosphere.

Determination of Calorific Value: BOMB CALORIMETER

- **Principle:** A known mass of fuel is burnt and the quantity of heat produced is absorbed in water and measured. Then the quantity of heat generated by burning a unit mass of the fuel is calculated.

- **Apparatus:** It consists of strong stainless steel vessel called Bomb which is capable of withstanding high pressure. It consists of oxygen inlet valve and two electrodes of battery. A silica crucible is kept inside the apparatus, in which weigh quantity of fuel is taken. A fuse wire of platinum is dipped in the fuel taken in the crucible and its ended is connected to battery. The bomb is placed in copper calorimeter containing known quantity of water. The copper calorimeter is surrounded by air jacket which is further enclosed in a vessel containing water. One electric stirrer for stirring the water is provided in the calorimeter. Calorimeter also contains one accurate Beckmann's thermometer for noting down the temperature. The material (X gms) to be combusted is put in a metal cup that is suspended in the bomb by two supports which are also part of the electrical circuit containing the fuse wire. The fuse wire spans across the top of the metal cup and when current is passed through the fuse wire, it heats up rapidly and ignites the fuel.

Working: The bomb is placed in a container with a known amount of water (W) together with a stirrer and thermometer. The stirrer is used to maintain a uniform temperature in the water and to aid heat transfer from the bomb. The thermometer measures the water temperature ($T_{1,}$ its range is 24°C to 30°C with 0.01°C precision). Between the container of water and the surrounding compartment of water (w), there is an air gap which is an excellent heat insulator. When the calorimeter is running, the temperature of the calorimeter body is automatically maintained at the same temperature as the container of water holding the bomb (T_2). This provides an adiabatic condition and thus no heat transfers to or from the container of water takes place except from the heat released in the bomb.


Pressure
gaug
Oxygen inlet valve
Battery
6 V
Valve
Electrodes
Fuse wire
Water
Oxygen
Cylinder
Stirrer
Water jacket
Fuse Wire
Beckmann's
thermometer
Calorimeter
Ring
Bomb
Crucible
Fuel
sample
Cottom
thread

$$HCV = \frac{(W + w)(T_2 - T_1)}{X} cal / gm$$

where HCV = Higher calorific value of a fuel; W = Mass of water in calorimeter; w = Water equivalent of calorimeter; T_1 = Initial temperature of water in calorimeter; T_2 =Final temperature of water in calorimeter and X = Mass of fuel sample taken.

LCV = (HCV – 0.09H ×587) cal/gm

$$(W + w)\frac{(T_2 - T_1 + T_c) - (C_S + C_N + C_F + C_C)}{X}$$

where, T_C = Cooling Correction; C_S = Correction for H_2SO_4; C_N = Correction for HNO_3; C_F = Corrections for fuse wire and C_c = Corrections for cotton thread.

According to Dulong's formula,

$$HCV = \frac{1}{100}\left[8080C + 34500\left[H - \frac{O}{8}\right] + 2240S\right] Kcal / Kg$$

Where C, H, O and S are percentages of carbon, hydrogen, oxygen and sulphur in the fuel respectively

LCV = (HCV – 0.09H ×587) cal/gm

Numerical: A sample of coal was found to have the following % composition by weight: C=75%, H=5.2%, O=12.1%, N=3.2% and ash=4.5%. Calculate GCV and NCV

$$\text{HCV} = \frac{1}{100}\left[8080C + 34500\left[H - \frac{O}{8}\right] + 2240S\right] Kcal/Kg$$

$$\frac{1}{100}\left[8,080 + 75 + 34,500\left(5.2 - \frac{12.1}{8}\right)\right] Kcal/Kg$$

= **7332.19 Kcal/Kg**

NCV = HCV-0.09H × 587

= 7332.19 – 274.716

= **7057.474 Kcal/Kg**

Numerical

- **Problem 1**
- In an actual test for determination of calorific value of fuel by bomb calorimeter the following data were obtained:
- Weight of silica crucible, with nichrome fuse = 3.481 gm
- Weight of crucible, nichrome fuse and fuel = 4.313 gm
- Weight equivalent of calorimeter = 750 gm of water
- Quantity of water in calorimeter = 1750 gm
- Rise of temperature of water = 2.96^{o} C
- Calculate the calorific value of the fuel.
- **Solution:**
- Weight of fuel burnt (X) = 4.313 − 3.481 = 0.832 gm
- Water equivalent of calorimeter (w) = 750gm
- Quantity of water taken (W) = 1750 gm
- Total water equivalent (W+w) = 2500 gm
- Rise in temperature of water $(T_2\text{-}T_1)$ = 2.96^{o} C

$$= \frac{(1750 + 750) \times (2.96)}{0.832}$$

HCV = 8894.23 cal/ gm or 8.9 Kcal /Kg Ans.

Solid Fuel- COAL

- Coal is a fossil fuel which is formed from decayed plants by exposure to heat and pressure in the earth's crust over hundreds of millions of years.
- Coal consist of C, H, N. O, S & P

Types of Coal:

1. Peat
2. Lignite
3. Bituminous
4. Anthracite

Properties of different type of coal

Coal Type	Depth of burial	Maximum temperature during burial	Moisture Content	Fixed Carbon Content
Lignite	0.2-1.5km	25-45 ^{0}C	30-50%	20-35%
Sub bituminous	1.5-2.5km	45-75 ^{0}C	10-30%	35-45%
Bituminous	2.5-6km	75-180^0 C	5-10%	45-80%
Anthracite	>6km	>180 ^{0}C	<5%	80-96%

ANALYSIS OF COAL

- (A) Proximate Analysis / Qualitative / Physical Analysis:
  - Moisture content
  - Volatile matter
  - Ash content
  - Fixed carbon
- (B) Ultimate Analysis / Quantitative Analysis / Chemical Analysis :
- (i) Carbon and Hydrogen:
- (ii) Nitrogen
- (iii) Sulphur
- (iv) Oxygen

CARBONIZATION OF COAL

- When the coal is heated strongly in absence of air, it loses volatile matter and is converted into white, lustrous, dense, strong, porous and coherent mass known as coke. The process of converting coal into coke is known as carbonization.

$$\text{Coal} \longrightarrow \text{Coke} + \text{Coal gas}$$

- Types of Carbonization:
- Low Temperature Carbonization
- High Temperature Carbonization

Comparison of the carbonization of coke at different temperatures

S.No	Characteristics	Lower temperature Carbonization	Higher temperature Carbonization
1	Carbonization temperature	500-700^{0}C	900-1200^{0}C
2	Percentage of coke produced	75-80%	65-75%
3	Volatile matter	5-15%	1-3%
4	Coal gas being produce mixture of CH_4, CO, NH_3	5-8%	17-20%
5	Calorific value of coal gas	6500-9500 Kcal/m^3	5400-6000 Kcal/m^3
6	Hardness of coke	Soft and smokeless	Hard and smoky
7	Percentage of straight chain hydrocarbon	Higher	Lower
8	Percentage of aromatic hydrocarbon	Lower	Higher
9	Use	Domestic Industrial	Industrial metallurgy

Liquid Fuel

- Crude Oil
- Petrol
- Diesel
- Kerosene

CRACKING

- The decomposition of higher hydrocarbons of high boiling point into lower hydrocarbons of low boiling point is known as cracking.
- It is done to obtain gasoline from higher hydrocarbons in case of liquid fuels

$$C_{10}H_{22} \longrightarrow C_2H_4 + C_3H_6 + C_5H_{12}$$

(Decane) (Ethene) (Propene) (Pentane)

- Types of Cracking
- 1. Thermal Cracking :a) Liquid phase b) Vapour phase
- 2. Catalytic Cracking : a) Fixed bed b) Moving bed

KNOCKING

- It is a sharp metallic sound similar to rattling of hammer which is produced in the internal combustion engine due to immature ignition of the air gasoline mixture.
- **Disadvantages of Knocking:**
- 1. It decreases the efficiency of engine.
- 2. It causes loss of energy.
- 3. Damages the piston and cylinder.
-
- **Relationship between Knocking and Structure of Hydrocarbon:** Knocking and chemical structure are closely related. The knocking tendency decreases with increase in the compactness of the molecules, double bonds and cyclic structures.
- The knocking increases with increase in the length of the hydrocarbon chain.
- n-heptane > n-hexane > n-pentane > n-butane
- The constituent of fuel to knock is in the following order.
- Straight chain paraffins> Branched chain paraffins > Olefins > Cycloparaffins (Naphthenes) > Aromatics

Prevention of Knocking

- The use of a fuel with higher octane rating .
- By adding antiknock agents such as TEL (Tetra ethyl lead)
- Increasing the amount of injected fuel.
- Reduction of cylinder pressure.

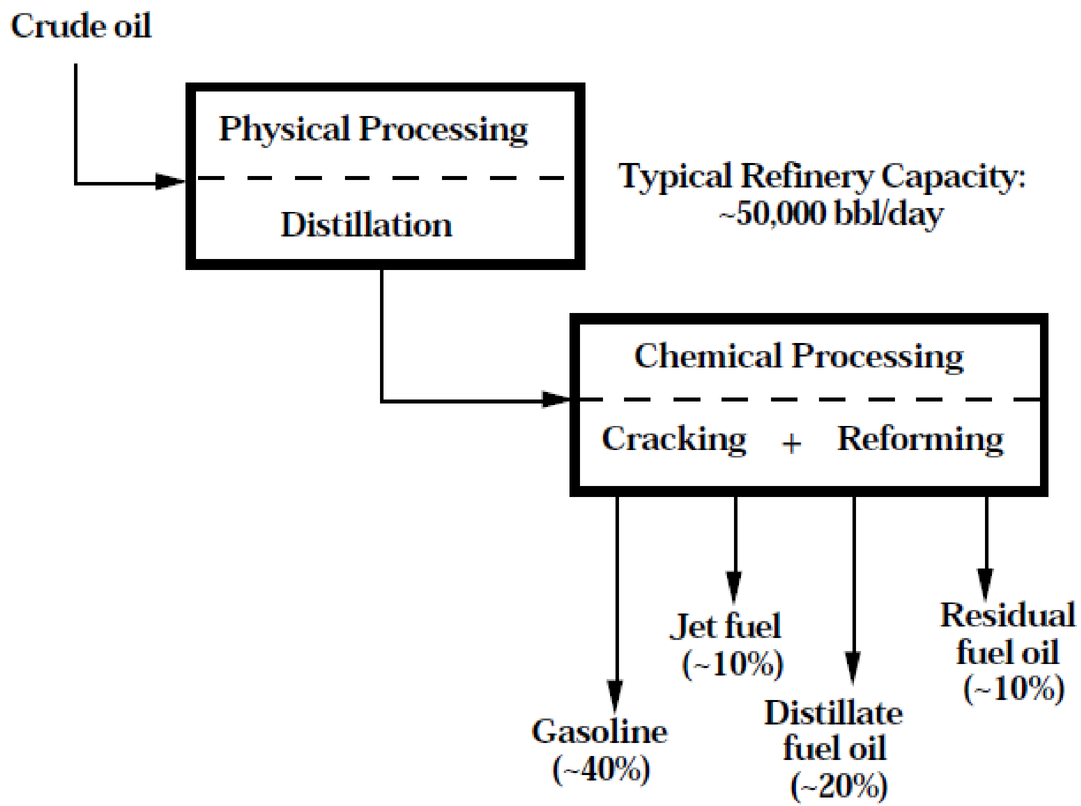
Retardation of spark plug ignition.

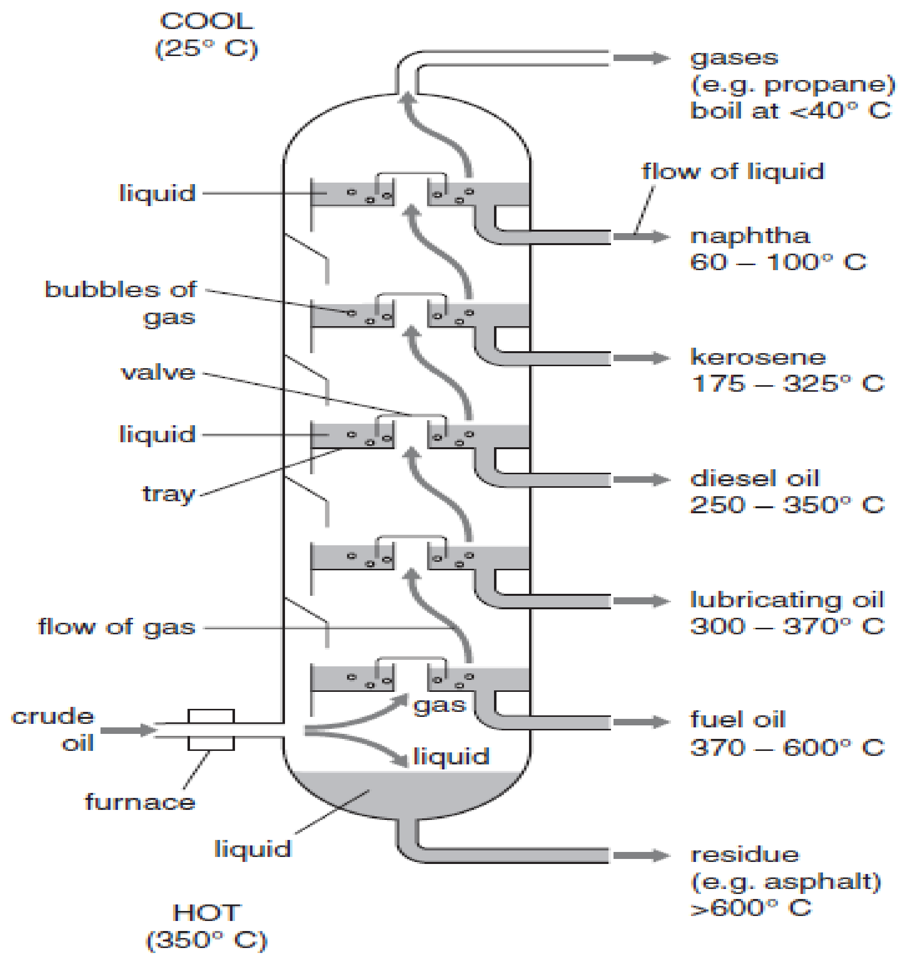
- By improving the combustion chamber design.
- Use of a spark plug of colder heat range.
- Correct ignition timing is essential for optimum engine. performance and fuel efficiency.

S.No.	Octane Number	Cetane number
1.	The percentage of iso-octane in a mixture of n- heptane and iso-octane is called octane number.	The percentage of hexadecane in a mixture of hexadecane and 2-methyl naphthalene is called cetane number.
2.	It is used for identifying quality of petrol.	It is used for identifying quality of diesel.
3.	Octane number of gasoline can be raised by addition of TEL [$(C_2H_5)_4$ Pb] and diethyl telluride[($(C_2H_5)_2$ Te].	Cetane number of diesel can be raised by addition of ethyl nitrite, isoamyl nitrite etc.
4 (a) (b)	$CH_3 - (CH_2)_5 - CH_3$ n- Heptane (Octane No. = zero) Knocks very badly iso-octane (Octane No. 100) Knocks very little	2- methyl naphthalene (Cetane No. = zero) knocks very badly n-Hexadecane (cetane No. = 100) Knocks very little
5	Straight chain hydrocarbon molecule are worst fuel, therefore low octane no.	Straight chain hydrocarbon molecule are best fuel , therefore high cetane no.
6.	Relation between octane no. of hydrocarbon and structure is- aromatics > cyclo alkane > alkene >branched alkane>straight chain alkane	Relation between cetane no. of hydrocarbon and structure is- n- alkanes > cyclo alkane > alkenes >branched alkanes > aromatics.
7.	Standard requirement- octane number of petrol should be at least 85 for motorcycle & cars and above 100 for aeroplanes and helicopter.	Standard requirement- cetane number of diesel should be 25 for low speed engine, 35 for medium speed engine and above 45 for high speed engine.

Fractional Distillation

- Crude oil (also called petroleum) is a mixture of different hydrocarbons. Many useful products can be made from these hydrocarbons.
- . The fractions are separated from one another using a process called fractional distillation. This process is based on the principle that different substances boil at different temperatures
- The main equipment is a tall cylinder called a fractionator (or fractional distillation column). Inside this column there are many trays, or horizontal plates, all located at different heights
- . Each tray collects a different fraction when it cools to its own boiling point and condenses. The crude oil is heated to at least 350°C, which makes most of the oil evaporate. The fluid then enters the column. As the vapour moves up through the fractionator, each fraction cools and condenses at a different temperature.
- As each fraction condenses, the liquid is collected in the trays. Substances with higher boiling points condense on the lower trays in the column. Substances with lower boiling points condense on the higher trays. The trays have valves, which allow the vapour to bubble through the liquid in the tray. This helps the vapour to cool and condense more quickly. The liquid from each tray then flows out of the column.


Crude oil
Physical Processing
Distillation
Typical Refinery Capacity:
~50,000 bbl/day
Chemical Processing
Cracking + Reforming
Gasoline
(~40%)
Jet fuel
(~10%)
Distillate
fuel oil
(~20%)
Residual
fuel oil
(~10%)


COOL
(25° C)
gases
(e.g. propane)
boil at <40° C
flow of liquid
liquid
naphtha
60 – 100° C
bubbles of
gas
kerosene
175 – 325° C
valve
liquid
diesel oil
250 – 350° C
tray
lubricating oil
300 – 370° C
flow of gas
crude
oil
gas
fuel oil
370 – 600° C
liquid
furnace
liquid
residue
(e.g. asphalt)
>600° C
HOT
(350° C)

Synthetic Petrol

- Synthetic fuel or synfuel is a liquid fuel, or sometimes gaseous fuel, obtained from syngas, a mixture of carbon monoxide and hydrogen, in which the syngas was derived from gasification of solid feed stocks such as coal or biomass or by reforming of natural gas.
- **OR** By **synthetic** fuels is meant substitutes for oil and natural gas manufactured from coal or from 'biological waste'. The substitutes are mainly for use as fuels for combustion engines in the transport sector.

Fischer-Tropsch process

- The **Fischer–Tropsch process** is a collection of chemical reaction that converts a mixture of carbon mono-oxide and hydrogen into liquidhydrocarbons. These reactions occur in the presence of metal catalysts, typically at temperatures of 150–300 °C (302–572 °F) and pressures of one to several tens of atmospheres.
- A variety of catalysts can be used for the Fischer–Tropsch process, the most common are the transition metals, cobalt, iron and ruthenium.

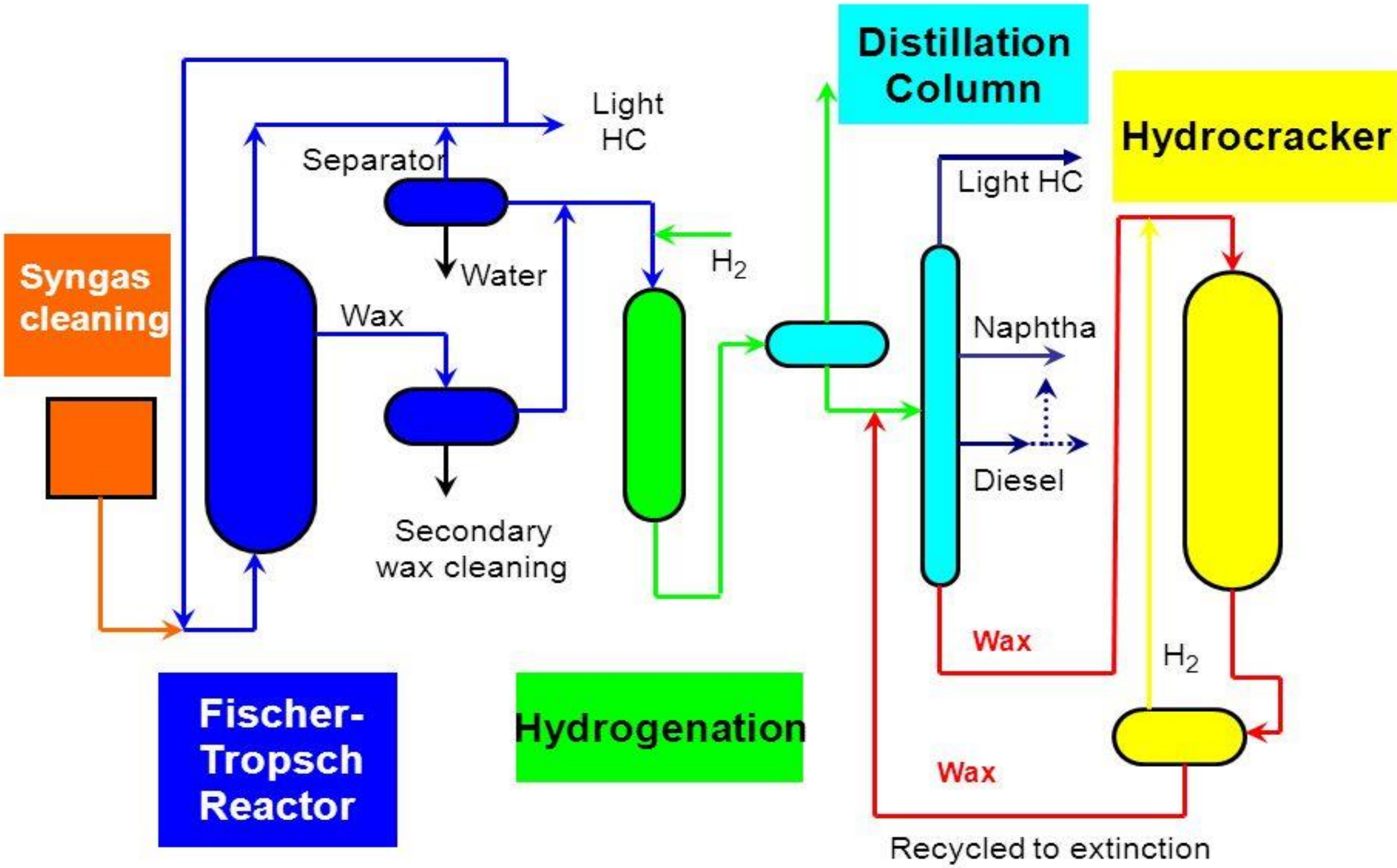
Reactions:

- Conventional Syngas Production
- $2CH_4 + O_2 \longrightarrow 4H_2 + 2CO$

- Syngas production from CO_2

- $CO_2 + CH_4 \longrightarrow 2H_2 + 2CO$
- $nCO + (2n+1)H_2 \longrightarrow C_nH_{2n} + nH_2O$

A SIMPLIFIED FT – PU Process Flow Diagram



Bergius process

- The **Bergius process** is a method of production of liquid hydrocarbon for use as Synthetic fuel by hydrogenation of high-volatile bituminous coal at high temperature and pressure. It was first developed by Friedrich Bergius in 1913. In 1931 Bergius was awarded the Nobel Prize in Chemistry for his development of high pressure chemistry.

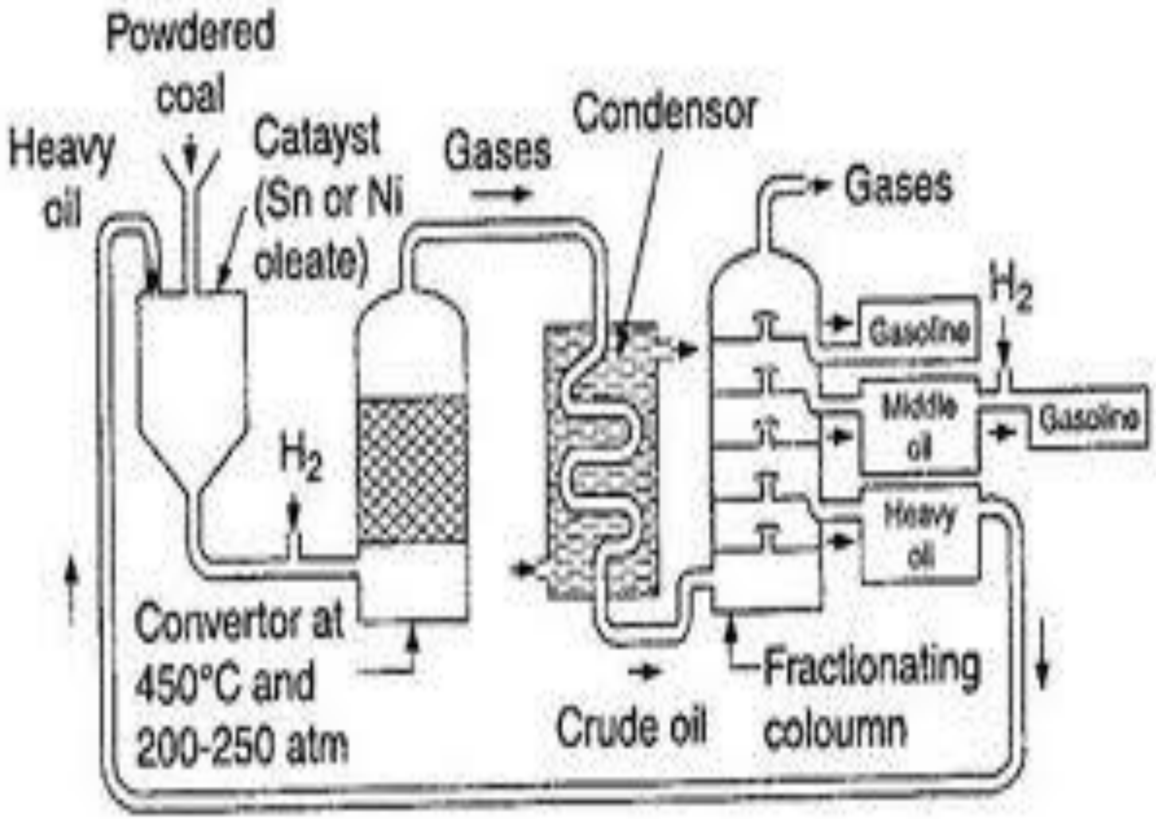
The coal is finely ground and dried in a stream of hot gas. The dry product is mixed with heavy oil recycled from the process. A catalyst is typically added to the mixture. A number of catalysts have been developed over the years, including tungsten or molybdenum sulfides, tin or nickel oleate are used. Alternatively, iron sulphides present in the coal may have sufficient catalytic activity for the process, which was the original Bergius process.

The mixture is pumped into a reactor. The reaction occurs at between 400 and 500 °C and 20 to 70 MPa pressure. The reaction produces heavy oils, middle oils, gasoline, and gases. The overall reaction can be summarized as follows:

$$nC + (n-x+1)\ H2 \longrightarrow CnH2n-2x+2$$

(where x = Degree of Unasaturation)

The immediate product from the reactor must be stabilized by passing it over a conventional hydrotreating catalyst. The product stream is high in naphthenes and aromatics, low in paraffins and very low in olefins. The different fractions can be passed to further processing (cracking and reforming) to output synthetic fuel of desirable quality. About 97% of input carbon fed directly to the process can be converted into synthetic fuel.


Powdered
coal
Heavy
oil
Cataryst
(Sn or Ni
oleate)
Gases
Condensor
Gases
H_2
Gasoline
Middle
oil
Gasoline
H_2
Heavy
oil
Convertor at
450°C and
200-250 atm
Crude oil
Fractionating
coloumn

Power Alcohol

- When ethyl alcohol is used as a fuel in internal combustion engine, it is called as power alcohol.
- Power alcohol is a mixture of 80% Petrol + 20% Ethanol + Small quantity of Benzene. It is used for the generation of power. Ethyl alcohol is mainly manufactured by fermentation of molasses, starch, carbohydrates on a large scale & cheaply. It can also be obtained from synthesis gas (CO, H2)
- $C_{12}H_{22}O_{11} \xrightarrow[\text{Yeast}]{} C_2H_5OH + CO_2$
- The ethyl alcohol obtained contains 95.5% alcohol & 4.5% water.
- This water is separated either by use of suitable dehydrating agent or by distilling it along with benzene.

ADVANTAGES OF POWER ALCOHOL:

1.Ethyl alcohol has good Ant knocking property and its octane number is 90.

2.It has property of absorbing any traces of water if present in petrol.

3.If a specially designed engine with higher compression ratio is used then the disadvantage and lower CV can be overcome.

4.It contains O atoms which help for complete combustion of power alcohol & the polluting emission of CO, hydrocarbon, particulates are reduced largely.

5.Use of ethyl alcohol in petrol reduces our dependence on foreign countries for petrol and saves foreign currency considerably.

6.Power alcohol is cheaper than petrol.

Disadvantages of Power Alcohol:

1. It has less calorific value
2. Less power output. More fuel is consumed
3. Ethyl alcohol is corrosive in nature.
4. It has poor cold weather starting characteristics due to low vapour pressure and evaporation

Combustion

- A combustion reaction is known as the reaction where all components in a compound combine with oxygen which then produces carbon dioxide and water. Combustion is commonly called burning.
- It is an exothermic reaction which means heat is produced
- $C_{(x)} H_{(y)} + O_2 \rightarrow y/2 H_2O_{(g)} + xCO_{2\,(g)}$ + Heat / Light
-

Combustion Reactions

- $C + O_2 \longrightarrow CO_2$
- 12 32 44 (By wt)
- $H_2 + 1/2O_2 \longrightarrow H_2O$
- 2 16 18
- $S + O_2 \longrightarrow SO_2$
- 32 32 64
- $CO + 1/2O_2 \longrightarrow CO_2$
- $CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

1.The composition of air is taken as 21% of O_2 and 79% of N_2 (by volume) and 23% of O_2 and 77% of N_2 (by weight).
2. The mean molecular weight of air is taken as 28.95 g/mole.
3. Density of air**:** The density of air at N.T.P. is 1,290 Kg. m^{-3} or 1.290×10^{-3} g cm^{-3}.
4.The composition of a solid or liquid fuel is usually expressed by weight whereas the composition of gaseous fuel is given by volume.
5.The masses of gaseous substances can be calculated by Gas laws and Avogadro's Law.
6. Avogadro's Law**:** 22.4 L (or 22,400 mL) of any gas at STP (i.e.0^0C and 760 mm pressure) have a mass equal to its 1mol.
7. Gas Law**:** The mass of any gas can be converted to its volume at certain temperature and pressure by using gas equation.
$PV = nRT$
8. Minimum oxygen required = Theoretical oxygen required – O_2 present in the fuel

1. Theoretical amount of oxygen required for complete combustion of 1 Kg of fuel

$$=\left[\frac{32}{12}\times C+\frac{16}{2}\left[H-\frac{O}{8}\right]+S\right]g$$

2. Theoretical (Min air) amount of air required for complete combustion of 1Kg of fuel is:

$$=\frac{100}{23}\left[\frac{32}{12}\times C+\frac{16}{2}\left[H-\frac{O}{8}\right]+S\right]g$$

3. Total air = Min. air required x 100+x/100

X= % of excess air

Q.1 A sample of coal was found to have the following % composition by weight: C=75%, H=5.2%, O=12.1%, N=3.2% and ash=4.5%. Calculate (i) the minimum amount of O_2 and air by weight necessary for complete combustion of 1 Kg of coal (ii) weight of air required; if 40% excess air is supplied (iii) gross and net calorific value of coal sample using Dulong's formula.

1 Kg of coal contains: C= 750 gms, H = 52 g, O_2= 121 g, N= 32g

Minimum wt. of O_2 required for complete combustion of 1Kg of coal:

$$= \left[\frac{32}{12} \times C + \frac{16}{2}\left[H - \frac{O}{8}\right] + S\right] g$$

= [2000 + 416 – 121] g = 2,295 g

Minimum wt. of air required = 2295 x 100/23

= 9978 g

(ii) Wt. of air required with 40% excess = 9978 x 140/100

=**13969 g**

Q. 2. **Calculate the weight and volume of air needed for complete combustion of 5 Kg of a coal containing 85% carbon, 10% hydrogen and rest oxygen.**

Solution : 5 Kg of coal contains

C = 4.25 Kg, O = 0.25 Kg, H = 0.500 Kg

Minimum weight of oxygen needed for combustion of 5 Kg of coal

$$= \left[\frac{32}{12} \times C + \frac{16}{2}\left[H - \frac{O}{8}\right] + S\right] g$$

= 11.33 + 4.000 − 0.25

= 15.083 Kg

Minimum weight of air needed for complete combustion

= 15.083 × 100/23

= **65.558 Kg or [65,558 gm]**

Now molecular weight of air is 28.94 gm

28.94 gm of air occupied a volume = 22.4 litre at N.T.P.

65558 gm = 22.4/28.94 × 65558

= 50,742.9 litre

= 50.7429 m^3

Q. 3 The percentage composition of sample of anthracite coal is C=90, H=3.5, O=3.0, N=1.0, S=0.5 and the remainder being ash (by weight). Estimate (i) minimum weight of air required for combustion of 1 Kg of this fuel, (ii) the composition of dry products of combustion by volume, if 50% excess air is supplied.

Solution:

1 Kg of coal contains C = 900 g H= 35g, O=30g, N=10g, S=5g and ash (by difference) =20g

Minimum wt. of O_2 required for 1 Kg of coal:

= 2655g

(i) Minimum wt. of air required for 1 Kg of coal

=

= 11543.48 g = **11.543 Kg Ans.**

Total air = 11.543 × 150/100

= 17.315 Kg

Difference of excess air = 17.315 − 11.543 = **5.772 Kg or 5772 g Ans.**

(ii) Calculation of weight of dry products of combustion with 50% excess air. Dry products obtained during the reaction are CO_2, SO_2, N_2, O_2

CO_2 = 44/12 x 900= 3300 g

SO_2 =64/32 x 5 = 10 g

N_2 = (77/100 x Total air) + Nitrogen present in fuel = 10g + 13332.72 g = 13342.72 g

O_2 = 5772 x 23/100 = 1327.56 g

Total wt of dry products= 3300+10+13342.72+1327.56= 17980.28 g