

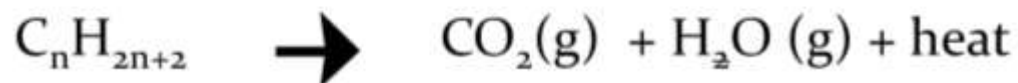
Fuels

A fuel is a combustible substance containing carbon as the main constituent which on proper burning gives a large amount of heat that can be used economically.

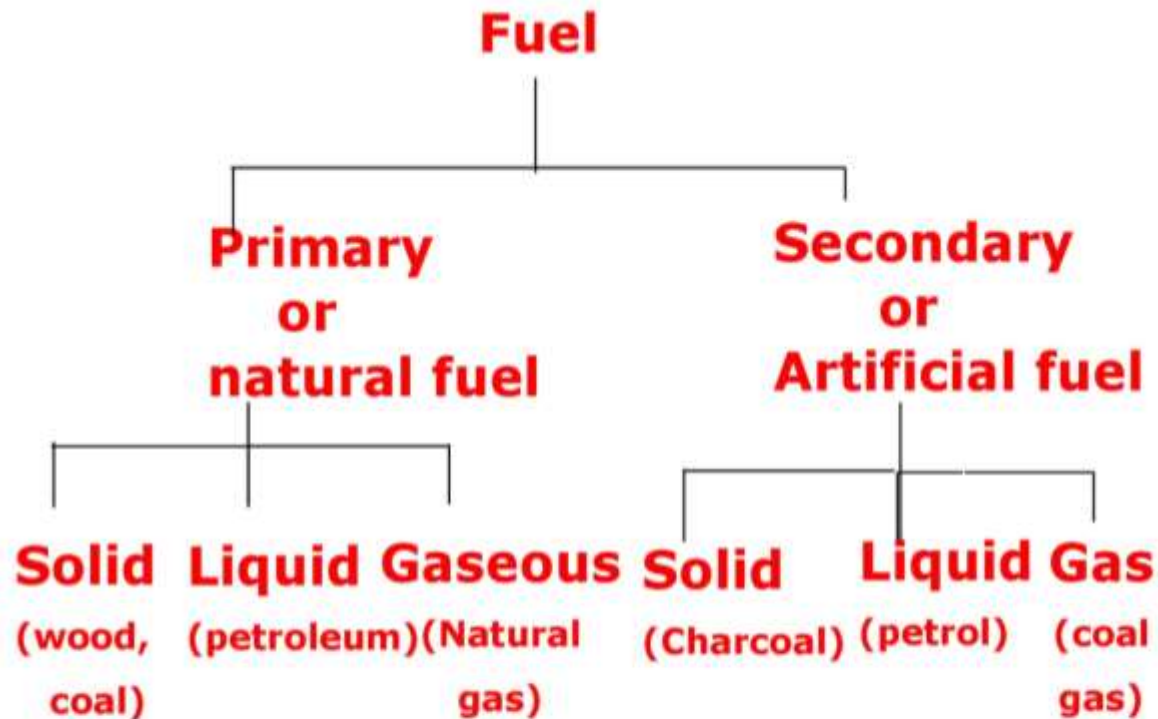
For example, wood, coal, kerosene, petrol, diesel and water gas.

Combustion is a chemical reaction in which a substance combines with oxygen producing heat, light and flame.

Combustion reaction of a fuel can be represented as follows



Classification of Fuels



Primary fuels are found in nature whereas

Secondary fuel are prepared from primary fuel by processing them in a number of ways.

Characteristics of Good Fuel

A good fuel should have

- high calorific value
- moderate ignition temperature
- low moisture content
- low non combustible matter content
- low cost and easy availability
- easy to transport and storage cost should be low
- products of combustion should not be harmful.
- burn in air without much smoke
- combustion should be easily controllable.

Calorific Value

Calorific value of a fuel is the total quantity of heat liberated when one unit of fuel is burnt completely.

Gross or Higher calorific value (G.C.V or H.C.V): It is the total quantity of heat liberated when one unit of fuel is burnt completely and products of combustion has been cooled to room temperature.

Net or Lower calorific value (N.C.V or L.C.V)): It is the total quantity of heat liberated when one unit of fuel is burnt completely and products of combustion has been permitted to escape.

$$\text{L.C.V} = \text{H.C.V} - \text{Latent heat of water vapour formed}$$

Theoretical calculation of Calorific value using Dulong's Formula

$$\text{H.C.V} = [8080C + 34500(H - O/8) + 2240 S]/100 \quad \text{kcal/kg}$$

Where,

C= % of carbon in the fuel

H= % of hydrogen in the fuel

O= % of oxygen in the fuel

S= % of sulphur in the fuel

And

Calorific value of carbon= 8080 kcal/kg

Calorific value of hydrogen= 34500 kcal/kg

Calorific value of sulphur= 2240 kcal/kg

$$\text{L.C.V} = \text{H.C.V} - \text{Latent heat of water vapour formed}$$

$$\text{LCV} = \text{HCV} - 0.09H \times 587 \text{ kcal/kg}$$

Units of Calorific Value

Units of calorific value	Solid fuel	Liquid fuel	Gaseous fuel
CGS method	cal/g	cal/g	cal/cm ³
MKS method	Kcal/Kg	Kcal/Kg	Kcal/m ³
FPS method	B.Th.U/lb	B.Th.U/lb	BTU/ft ³
SI method	Joule/Kg	Joule/Kg	Joule/m ³

1 Kcal/kg = 1.8 B.Th.U/lb

1 Kcal/m³ = 0.1077 B.Th.U/ft³

The Calorie, a unit of heat may be defined as, the heat required to raise the temperature of **1kg of water from 15°C to 16°C**.

A British Thermal Unit may be defined as, the heat required to raise the temperature of **one pound of water from 60°F to 61°F**.

$$1\text{BTU} = 2.252\text{Kcal} = 2252\text{cal}$$

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

$$1\text{kcal} = 3.968\text{BTU}$$

Centigrade Heat unit is the heat required to raise the temperature of **1pound water through 1 degree centigrade**.

$$1\text{kcal} = 2.2\text{CHU} = 3.968\text{BTU}$$

$$1\text{kcal/kg} = 1.8\text{BTU/lb}$$

$$1\text{kcal/m}^3 = 0.1077\text{BTU/ft}^3$$

$$1\text{BTU/ft}^3 = 9.3\text{kcal/m}^3$$

Numerical:

1. Convert 450cal/gm into- a. kcal/kg b. BTU/lb c. kcal/m³ d. BTU/ft³ e. CHU/lb.

Solution: a. 450kcal/kg b. 810BTU/lb c. d. e. 449.09CHU/lb

2. Calculate the gross and net calorific values of a coal sample having the following composition C = 80%; H = 7%;O = 3%; S = 3.5%; N = 2.5% and ash 4.4%

Solution

$$(I) \text{ G.C.V} = 1/100[8080*\%C+34500(\%H - O/8)+2240*\%S] \text{ kcal/kg}$$

$$= 1/100[8080*80+34500(7 - 3/8)+2240*3.5] \text{ kcal/kg}$$

$$= 8828.0 \text{ kcal/kg}$$

$$(II) \text{ N.C.V} = \text{G.C.V} - [0.09H*587] \text{ kcal/kg}$$

$$= 8828 - [0.09*7*587] \text{ kcal/kg}$$

$$= 8458.2 \text{ kcal/kg}$$

Numerical:

3. A sample of coal contains: C= 60%, O= 33%, H= 6%, S= 0.5%, N= 0.3%, Ash= 0.2%. Calculate GCV and NCV.

Solution: GCV= 5506.075Kcal/kg, NCV= 5216.095Kcal/kg

4. A sample of coal contains C= 70%, O= 8%, N= 3%, S= 2%, Ash= 7%. If LCV is 8277.50Kcal/kg, find HCV and %H.

Solution: %H= 9.84 HCV= 8750.60 Kcal/kg

5. A sample of coal contains C= 61%, H= 6%, S= 0.5%, N= 0.2%, Ash= 0.3%. Calculate GCV and NCV.

Solution: %O= 32 GCV= 4250 Kcal/kg NCV= 3933.02 Kcal/kg

Comparison of Solid, Liquid and Gaseous Fuels

Solid fuel	Liquid fuel	Gaseous fuel
1. Calorific value: Their calorific value is low.	Their calorific value is high	Their calorific value is highest.
2. Pollution: Their ash content is high and they produce a lot of smoke on burning.	Their ash content is low and they burn without smoke.	They are almost pollution free; they burn without smoke and ash less.
3. Ignition temp and fire hazard: They possess moderate ignition temperature	Their ignition temp is low so there is a chance of fire hazard.	They have a very low ignition temp so they are highly inflammable and chances of fire hazard is highest.
4. Cost: Their production cost is low.	Cost is relatively higher than solid fuel.	They are more costly compared to solid and liquid fuel.

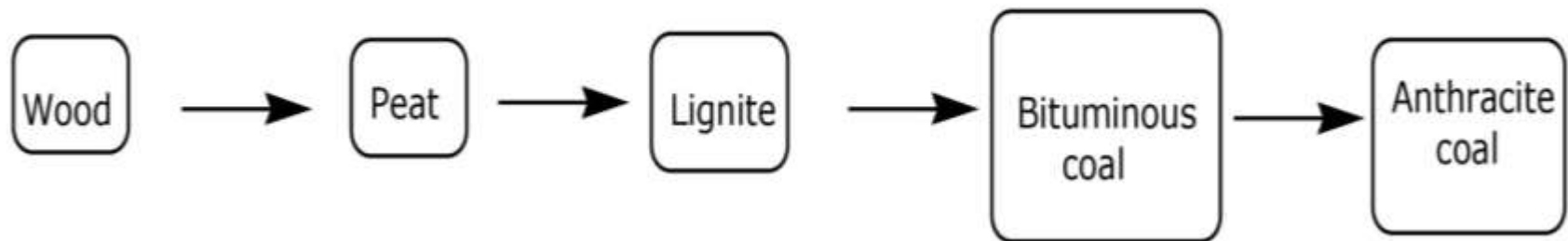
Solid fuel	Liquid fuel	Gaseous fuel
5. Transportation: They are easy to transport through normal carriage so cost is low.	They can be transported through pipelines hence it is more costly.	They can be conveyed through pipelines hence costly.
6. Storage Their storage needs lot of space but there is no risk.	Costly special storage tank is required for storing and safety precaution has to be taken to prevent fire hazard as most of them are highly inflammable and volatile	They can be compressed in cylinder so storage doesnot need lot of space. Safety precaution has to be taken to prevent fire hazard as they are highly inflammable and volatile.
3. Mode of operation during combustion: Their thermal efficiency is low and ignition temperature is high so large proportion of heat is wasted during combustion. They require a large excess of air for complete combustion. But the combustion operation cannot be controlled easily.	Their ignition temp is low so firing is easier and fire can be extinguished by stopping liquid fuel supply. The flame produced by burning can be easily controlled by adjusting fuel supply.	Their ignition temp is lowest so firing is very easy. The flame produced by burning can be easily controlled by adjusting fuel supply.

Solid Fuel

Classification of Coal

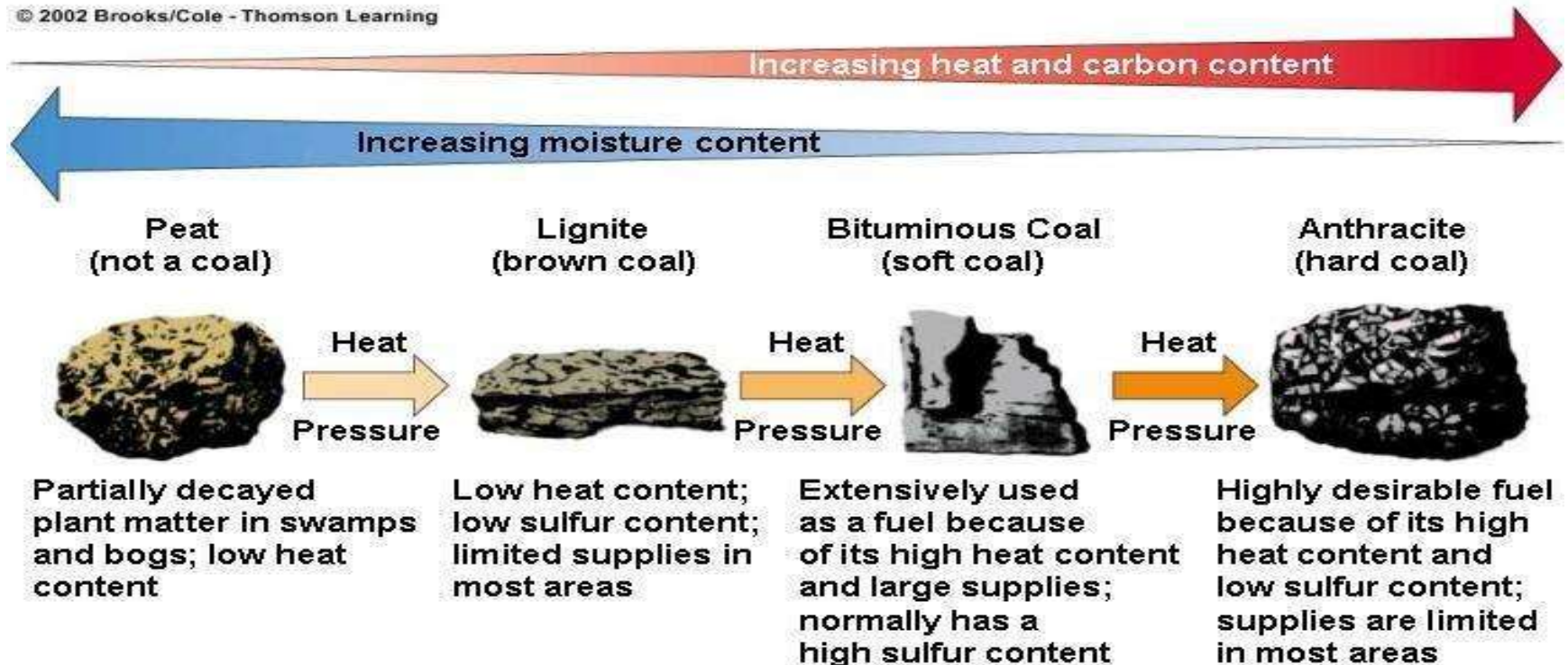
Coal is a primary solid fuel which occurs in nature in very impure form of carbon. It is a fossil fuel.

Wood, peat, lignite, bituminous and anthracite are the different stages in the conversion of wood to coal. Carbon content is highest in anthracite coal.



Coal formation process

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Classification of Coal

	Wood	Peat	Lignite	Bituminous coal	Anthracite coal
% of Moisture content	25	25	20	4	1.5
% of Carbon content	50	57	60-80	83	93.3
% of Hydrogen content	6	5.7	5	5	3
Calorific value (Kcal/kg)	4000-4500	4500-5000	6500- 7000	8100- 8600	8650- 8700

Analysis of coal:

The purpose is to-

1. To decide the price of coal.
2. To determine the quality of coal.
3. To specify the use of coal for a particular purpose.
4. To calculate the theoretical calorific value of coal.
5. To calculate the air requirement for complete combustion of coal and design the furnace fir box suitably.

Analysis of coal sample is required to access the quality of coal.

(A) Proximate analysis (PA): It is the process of determination of moisture, volatile matter, ash and fixed carbon content.

(B) Ultimate analysis (UA): It is the process of determination of composition of various components of coal which includes the determination of % of C, H, S, N, O and ash content. It is necessary for utilization of coal for industrial purpose.

The **significance** of various parameters of proximate coal analysis:

Moisture :

Moisture increases transportation, handling, storage cost

Moisture decreases the heat content per kg of power plant coal

Moisture increases heat loss due to evaporation and superheating of vapor

Moisture helps in binding the fines

Moisture helps in radiation heat transfer

Volatile matter:

Volatile matter also contributes to the heating value of coal

Increase in percentage of volatile matter in coal proportionately increases flame length (smoky flame) and helps in easier ignition of coal

Sets of minimum limit of furnace height and volume

Influences secondary oil support

Ash:

Ash is an impurity which will not burn

Ash content is important in design of furnace grate, combustion volume, pollution control equipment (ESP) and Ash handling plant

Ash increases transportation, handling, storage cost

Ash affects combustion efficiency and boiler efficiency

Ash causes clinkering and slagging problems in boiler

Fix carbon:

Fix carbon acts as a main heat generator during burning.

Fix carbon gives a rough estimate of heating value of coal

PROXIMATE ANALYSIS OF COAL :

Procedure:

Determination of Inherent Moisture: Transfer about 1g (W_{coal}) of powdered air-dried coal sample into a previously weighed silica crucible. Place the open crucible with sample in an *electric oven* and heat it at about **105 – 110°C** for an **hour**. Take out the crucible after one hour from the oven and cool it in a **desiccator** (containing moisture absorbing anhydrous calcium chloride). Then weigh the crucible with sample. Calculate the loss in weight.

Weight before heating – Weight after heating = Loss in weight of coal

$$\% \text{Moisture} = \frac{\text{Loss in weight}}{\text{Weight of Coal}} \times 100$$

ii) Volatile matter: The dried sample of coal left in the crucible in step (i) is then covered with a lid and placed in a muffle furnace, maintained at 950°C . The crucible is taken out after 7 minutes of heating. It is cooled first in air then in a desiccator and finally weighed.

$$\% \text{ Volatile matter} = \frac{\text{Loss in weight}}{\text{Wt. of coal taken}} \times 100$$

Determination of ash

- Coal sample of accurate weight in a crucible is heated in muffle furnace at **700+50 degree** Celsius for $\frac{1}{2}$ an hour. Crucible is taken out and cooled first in air and then in **desiccators** and **weighed**.
- **% of ash** = $\frac{\text{weight of ash left} \times 100}{\text{weight of coal taken}}$

(2) **Fixed carbon content:** It is determined indirectly by deducting the sum of total moisture, volatile matter and ash content from 100.

$$\%FC = 100 - (\%M + \%VM + \%Ash)$$

Numerical:

A sample of coal is analyzed as follows: Exactly 2.5 g was weighted into silica crucible. After heating for an hour at 110°C, the residue weighed 2.415g. The crucible next was covered with a vented lid and strongly heated for exactly seven minutes at 950°C. The residue weighed 1.528g. The crucible was then heated without the cover, until a constant weight was obtained. The last residue was found to weigh 0.245g. calculate the percentage result of above analysis.

Significance of Ultimate Analysis

1. Greater the percentage of carbon and hydrogen, better is the coal in quality and calorific value. However, hydrogen is mostly associated with the volatile matter and hence, it affects the use to which the coal is put to.
2. Nitrogen has no calorific value and hence its presence in coal is undesirable. Thus, a good quality coal has very little nitrogen content.
3. Sulphur is usually present to the extent of 0.5–3.0% and is derived from ores like iron pyrite and gypsum, etc., mines along with the coal. Sulphur, although contributes to the heating value of coal, on combustion it produces acids which have harmful effects of corroding the equipment and also causes atmospheric pollution.
4. Oxygen content decreases the calorific value of coal. High oxygen content coals are characterized by high inherent moisture content, low calorific value and low coking power. Moreover, oxygen is in combined form with hydrogen in coal and thus, hydrogen available for combustion is lesser than actually present.

Ultimate Analysis

i) Carbon and Hydrogen (Combustion Method):

An accurately weighed coal sample (1-2g) is burnt in a current of oxygen in combustion apparatus. As a result C and H of the coal are converted into CO_2 and H_2O respectively. These are absorbed respectively in KOH and CaCl_2 tubes of known weights. The increase in the weights of KOH and CaCl_2 tubes corresponds to the amount of CO_2 and H_2O formed respectively,

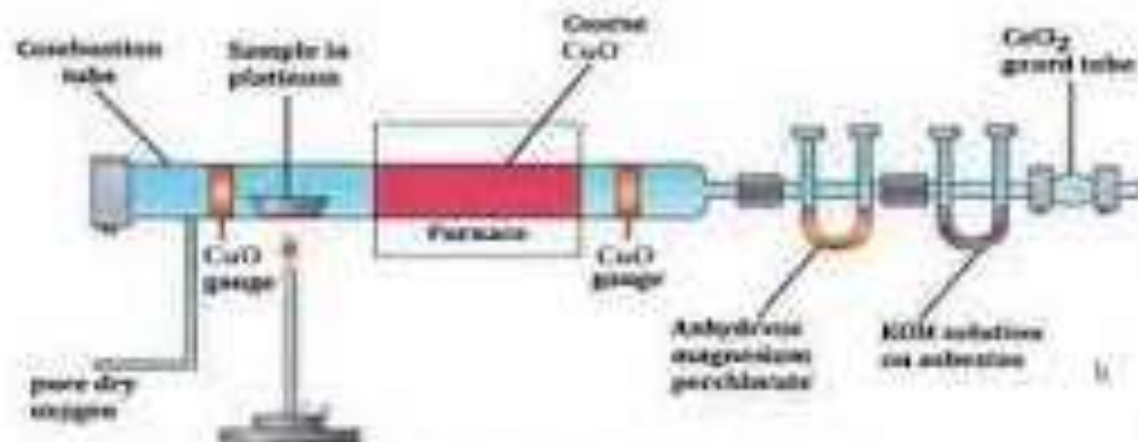
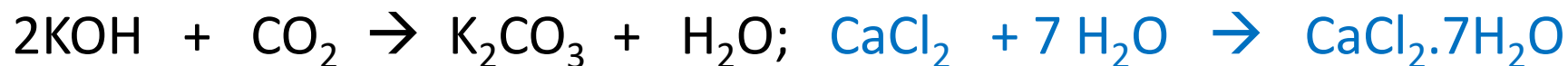
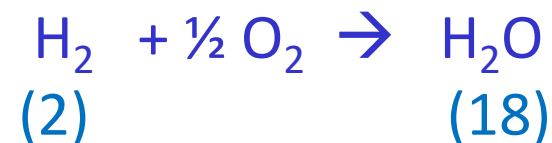
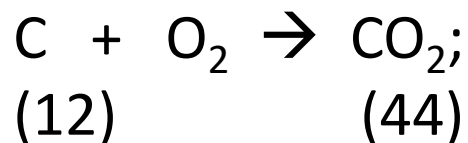


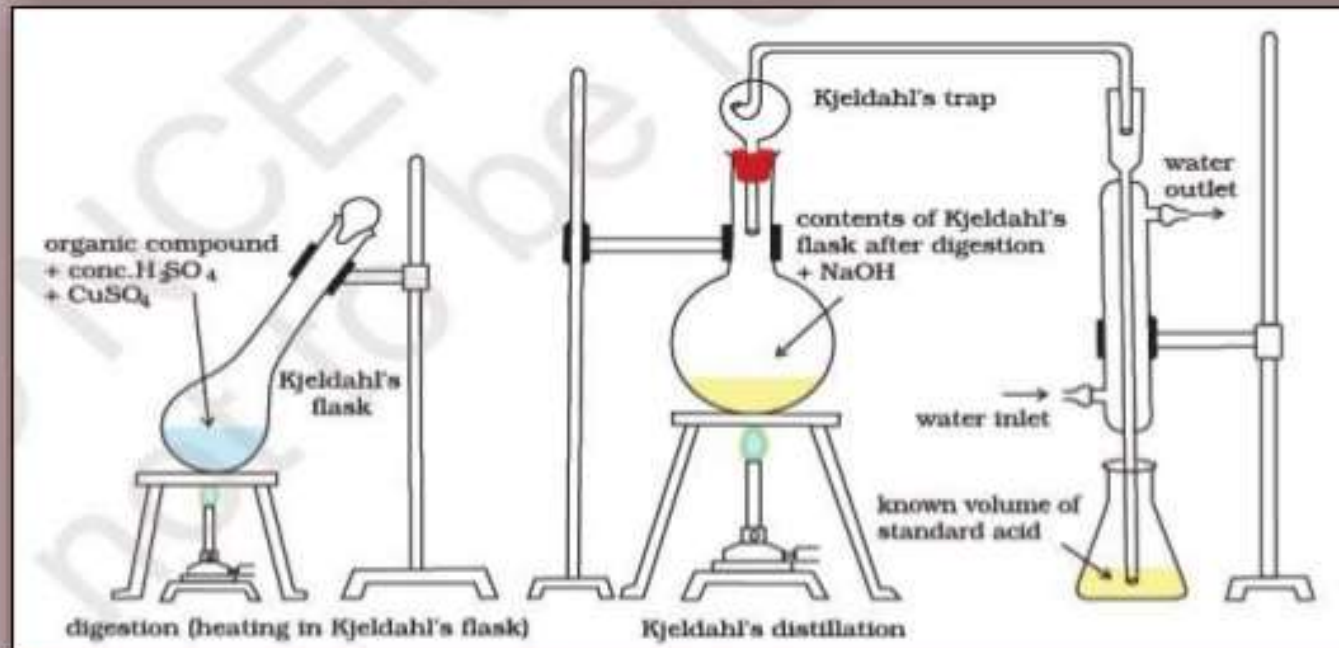
Fig 11.2 Estimation of Carbon and Hydrogen



$$\text{So, \%C} = \frac{\text{Increase in wt. of KOH tube} \times 12 \times 100}{\text{Wt. of coal sample} \times 44}$$

$$\text{\%H} = \frac{\text{Increase in wt. of CaCl}_2 \text{ tube} \times 2 \times 100}{\text{Wt. of coal sample} \times 18}$$

Determination of Nitrogen



- 1g of accurately weighed powdered coal is heated with conc. H_2SO_4 in kjeldahl flask.
- It is treated with excess KOH .

- Liberated ammonia is distilled over and absorbed in a known **volume of standard** solution of acid.
- Unused acid is determined by back titration with standard **NaOH**.

% of N is

$$\frac{\text{volume of acid used} \times \text{normality} \times 1.4}{\text{weight of coal sample taken}}$$

$$\% \text{ of N} = \frac{\text{Volume of acid used} \times \text{Normality} \times 1.4}{\text{weight of coal taken}}$$



Let weight of coal taken = W gm.

Vol of N/10 NaOH required for blank Rdg = Y ml.

Vol. of N/10 NaOH required = x ml (to titrate unreacted acid)

Vol. of N/10 acid reacted with ammonia = (y-x) ml.

Vol. of N/10 ammonia = (y-x) ml.

1000 ml of 1N ammonia solution = 17 gm of NH_3

1000 ml of 1N NH_3 Solution = 14 gm of N.

1000 ml of 0.1N NH_3 solution = 1.4 gm of N.

$$\therefore (y-x) \text{ ml of } 0.1\text{N } \text{NH}_3 \text{ solution} = \frac{1.4(y-x)}{1000} \text{ gm of N}$$

$$W \text{ gm of coal contains } \frac{1.4(y-x)}{1000} \text{ gm of N.}$$

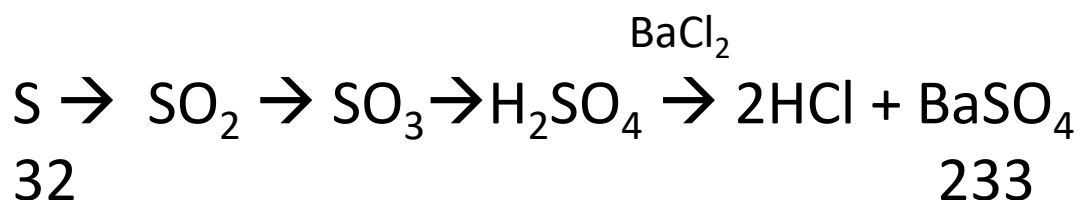
$$\therefore 100 \text{ gm of coal contains} = \frac{1.4(y-x)}{1000} \times \frac{100}{w} = \% \text{ N} = \frac{1.4(y-x)}{10 \times w}$$

OR

$$\% \text{ of N} = \frac{\text{vol. of acid used} \times \text{normality} \times 1.4}{\text{weight of coal taken}}$$

Determination of Sulphur:

Take 10ml of distilled water in a bomb calorimeter. Burn the known weight of powdered and air dried coal sample in it. Collect the washings in a beaker and add barium chloride solution to it. Filter the precipitate of barium sulphate formed. Dry it and weigh it. Calculate the %S as-



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

Determination of ash and oxygen

- Coal sample of accurate weight in a crucible is heated in muffle furnace at **700+50 degree** Celsius for ½ an hour. Crucible is taken out and cooled first in air and then in **desiccators** and **weighed**.
- **% of ash** =
$$\frac{\text{weight of ash left} \times 100}{\text{weight of coal taken}}$$
- **% of oxygen is**
100-percentage of (C+H+S+N+Ash)

Numerical:

1. 0.2g of coal sample is burnt. The gaseous products are absorbed in potash bulb and calcium chloride tube of known weight. The increase in weight of potash bulb and calcium chloride tube are 0.66gm and 0.08gm respectively. Calculate %C and %H. (Solution: C= 90%; H= 4.44%)

2. 3gm of coal was heated in Kjeldahl's flask and ammonia formed was absorbed in 40ml of 0.5N acid. After absorption, the excess acid required 18.5ml of 0.5N KOH for neutralization. 2.3gm of same coal sample gave 0.35gm BaSO_4 ppt. Calculate %N and %S. (N= 5.01%; S= 2.089%)

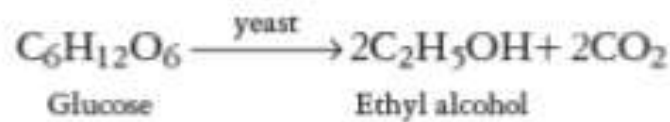
Power Alcohol and Synthetic Petrol

Power Alcohol

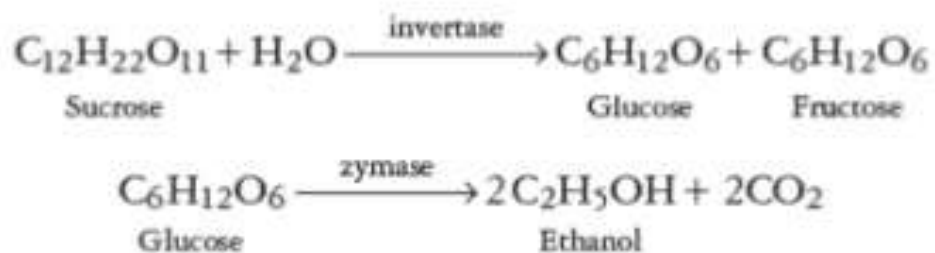
Ethyl alcohol is used as additive to motor fuels. When blended with petrol at concentrations of 5–10%, it is called power alcohol. The addition of alcohol to petrol increases its octane number.

Manufacture of Ethanol

1. By fermentation



2. Using Molasses as raw material



The advantages of power alcohol are as follows:

1. Ethyl alcohol is a good antiknocking agent and power alcohol has octane number 90, while that of petrol is 65.
2. Any moisture content present is absorbed by alcohol.
3. Ethyl alcohol contains oxygen atoms, which help for complete combustion of power alcohol and the polluting emissions of CO, hydrocarbon, particulates are largely reduced.
4. Power alcohol is cheaper than petrol.

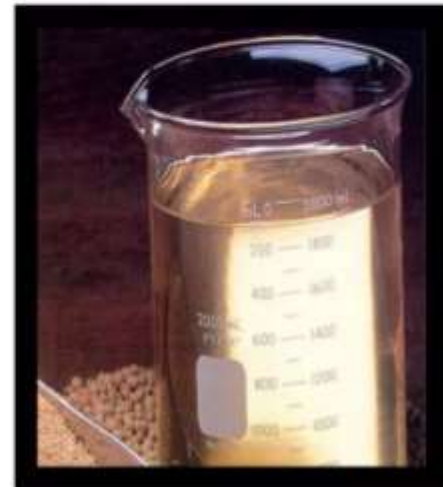
The disadvantages of power alcohol are as follows:

1. Ethyl alcohol has calorific value 7000 cal/g much lower than that of petrol which has 11500 cal/g. However, this problem could be overcome by using a specially designed engine with higher compression ratio.
2. The output of the power generated is reduced up to 35%.
3. It has high surface tension and its atomization is difficult, especially at lower temperature, thereby causing starting trouble.
4. It may undergo oxidation reaction to form acetic acid, which corrodes engine parts.
5. As it contains oxygen atoms, the amount of air required for complete combustion is less, therefore, the carburetor and engine need to be modified.

Bio-Diesel

Biodiesel refers to a non-petroleum-based diesel fuel consisting of short chain alkyl (methyl or ethyl) esters, made by Transesterification of vegetable oil or animal fat , which can be used (alone, or blended with conventional petro-diesel) in unmodified diesel-engine vehicles.

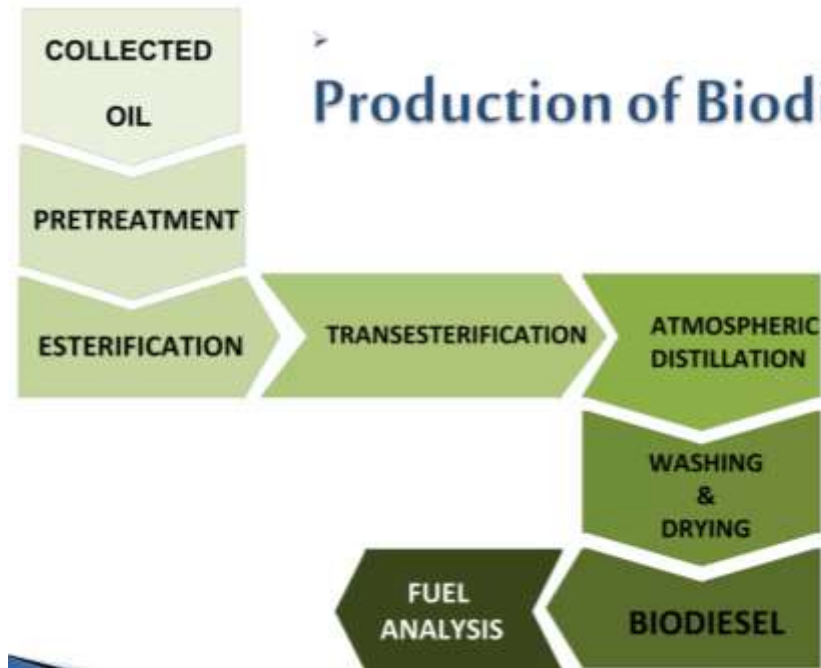
"**Biodiesel**" is standardized as mono-alkyl ester.



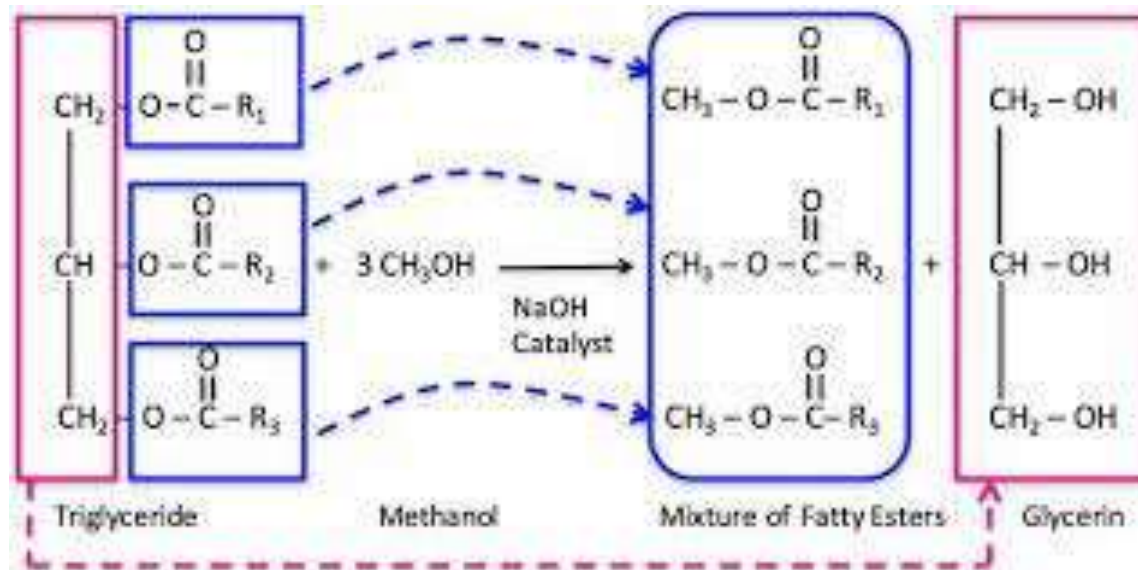
Why biodiesel

- Globally, transportation accounts for 25% of energy demand and nearly 62% of oil consumed.
- The generation of electricity is the single largest use of fuel in the world.
- More than 60 % of power generated comes from fossil fuels.
- Security Of Supply
- Reduction Of Green House Gas Emissions
- Social Structure & Agriculture

➤ Production of Biodiesel



- This is the process of separating the fatty acids from their glycerol backbone to form biodiesel and glycerine.
- Transesterification is the reversible reaction of oil with an alcohol (methanol or ethanol) to form fatty acid alkyl esters and glycerol.
- The vegetable oil molecules is reduced to about 1/3rd its original size, lowering its viscosity, making it similar to diesel.



Bio-Diesel

Uses of Biodiesel

- Electricity production
- Transportation
 - Railways
 - Ships
 - Automobiles

Railway usage

- The British businessman Richard Branson's Virgin Voyager train number 220007 Thames Voyager, billed as the world's first "biodiesel train".



Indian Initiatives

- National Mission on Biodiesel has been launched by GOI
- State Governments designated special authorities/bodies to manage
- Ministry of Petroleum and Natural Gas notified biodiesel purchase policy
- Government Institutes are working on technology and promotion
- Public and private sectors are working on processing and end use
- The former President of India, **Late Dr. Abdul Kalam**, is one of the strong advocates of Jatropha cultivation for production of bio-diesel.

Biodiesel : First trial run on train

- First successful trial run of a superfast passenger train was conducted on Dec 31, 2009
- Delhi - Amritsar Shatabdi Express used 5% of biodiesel fuel.
- Railway annual fuel bill = Rs 3400 crore (for Diesel)
- 10% mixture with Diesel = reduced
(Rs.300-400 crore / annum)
- 5% substitution is accepted.
- The **State Bank of India** provided a boost to the cultivation of Jatropha in India by signing a MoU with **D1 Mohan**, a joint venture of D1 Oils plc, to give loans to the tune of **1.3 billion rupees to local farmers** in India.

Interesting Practicalities States

- Andhra Pradesh has entered into a formal agreement with **Reliance Industries** for Jatropha planting.
 - The company has selected 200 acres (0.81 km²) of land at Kakinada to grow Jatropha for **high quality bio-diesel fuel**.
- Chhattisgarh has decided to plant 160 million saplings of Jatropha in all its 16 districts during 2006 with the aim of becoming a **bio-fuel self-reliant state by 2015**.

Maharashtra-

Major Issues

- Land Availability
 - Certified High Yielding Varieties
 - Plant Health
 - Availability of labor
 - Irrigation
 - Costs
- On Nov 2005, the Maharashtra Government aimed to cultivate Jatropha on 600 km² in the state.
 - September 2007-**Hindustan Petroleum Corporation Limited(HPCL)** joined hands with the **Maharashtra State Farming Corporation Ltd(MSFCL)** for a Jatropha seed-based bio-diesel venture.
 - Jatropha plant would be grown on 500 acres (2 km²) in Nashik and Aurangabad.

Advantages

- Bio diesel is environmental friendly.
- It can help reduce dependency on foreign oil.
- It helps to lubricate the engine itself, decreasing engine wear.
- It offers similar power to diesel fuel.
- It is safer than conventional diesel.
- It can be made from waste products.
- It can be made at home easily.

Disadvantages

- Its storage for long period is not suitable for engine operation.
- It becomes gel in cold weather.
- It has water content. (Hygroscopic)
- It has higher (10%) Nox emissions.
- It decreases horsepower. (25%)

Conclusion

- By mixing of 20 per cent biodiesel with diesel will help India to save 7.3×10^6 tones of diesel per year.
- In India about 33 million hectares of wasteland is available and can effectively be used for cultivation of jatropha plants.
- It offers business possibility to agricultural enterprises and rural employment.
- Biodiesel is least-cost-strategy to comply with state and federal regulations.
- Use of biodiesel does not require major engine modifications. The only thing that changes is air quality.
- Biodiesel has positive attributes such as increased cetane, high fuel lubricity & high oxygen content.
- Biodiesel reduces by as much as 65 % the emission of small particles of solid combustion products.
- The ozone (smog) forming potentials of hydrocarbons is less than diesel fuel.
- Sulfur emissions are essentially eliminated with pure biodiesel .
- Biodiesel contain no petroleum, but can be blended with conventional diesel fuel.
- These fuel can be used in any diesel engine without any modification.
- Biodiesel is degradable , non toxic and free from sulphur and lead.