Fuels and Combustion

Lecture 1

- Introduction
- Definition
- Classification of fuels
- Calorific Value and its units

Introduction

- A chemical fuel is defined as a combustible substance containing carbon as the main constituent, which on complete combustion gives large amount of heat that can be used economically for domestic and industrial purposes.

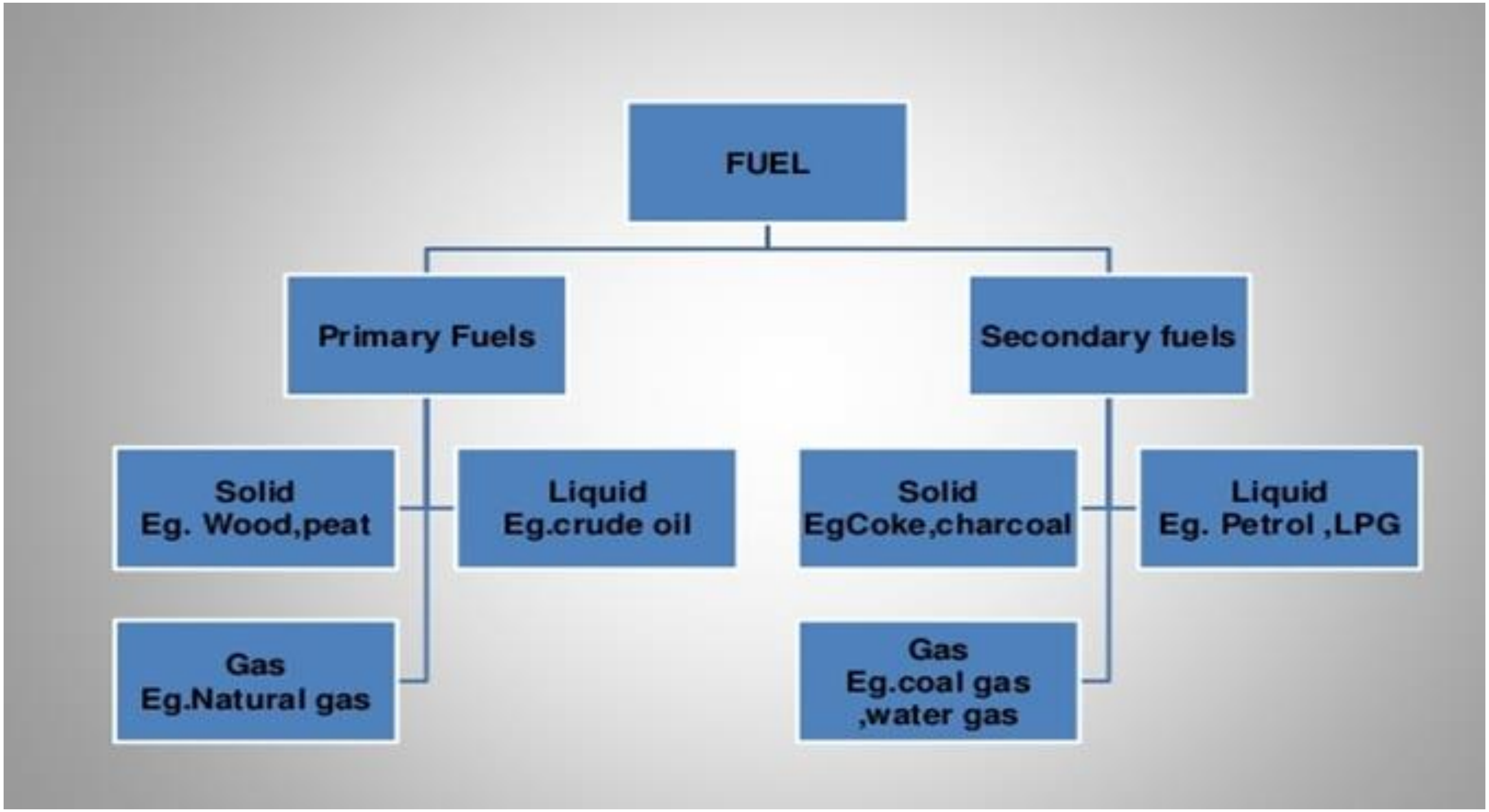
Different Energy Sources

- Non-renewable Fossil Fuels
- Renewable Sources

Characteristics of an ideal fuel

- **High Calorific value**
- **Moderate ignition temperature**
- **Low moisture content**
- **Low ash content**
- **Moderate velocity of combustion**
- **Less hazardous combustion products**
- **Low cost**
- **Easy Storage**

Classification of fuels



Calorific value

- Determination of Calorific Value is required to grade a fuel and assess its quality

- Calorific value of a fuel is the total quantity of heat liberated on burning of Unit quantity of Fuel

- **Units**

(1) CGS: Calorie/g

(2) SI unit: Joule/g

(3) British Thermal unit/pound (B.T.U./lb)

1 Calorie = 4.187 J

1 B.T.U. = 252 cal = 0.252 kcal   1 kcal = 3.968 B.T.U.

GCV

- **Gross Calorific Value (GCV)**

  GCV of a fuel can be defined as the total amount of heat obtained on complete combustion of unit mass of a solid or liquid fuel or unit volume of a gaseous fuel (STP) and on cooling the products of combustion to 15°C.

- Gross Calorific Value is also known as Higher Calorific Value (HCV)

NCV

Net Calorific Value (NCV)

NCV is defined as the amount of heat obtained practically on complete combustion of unit mass of solid or liquid fuel or unit volume of a gaseous fuel at STP and the products of combustion are allowed to escape with some heat.

- NCV is also called as lower calorific value (LCV)

$$GCV = NCV + 0.09 \times x \times 587\ cal/gm$$

Lecture 2

- General Principle of Calorimetry

- Methods of determination of calorific value

- Bomb calorimeter
- Principle
- Construction
- Working
- Formula
- Corrections
- Numericals

Calorimetry

- **Calorimeter works on Law of Conservation of Energy**
- **A calorimeter is used for measuring the amount of heat released or absorbed in chemical or physical reactions.**
- **It can determine**

a. **heat content**

b. **latent heat**

c. **specific heat**

GCV Determination

- **Depending on the state of the fuel, there are two methods of determination of CV**

A. Bomb Calorimeter (Solid/Non-volatile fuels)

B. Boy's Calorimeter (Volatile/ Gaseous fuels)

Bomb Calorimeter

- **Principle of Bomb Calorimeter**

  A known weight of solid / non-volatile liquid fuel is burnt in the presence of excess oxygen in the closed pot, and the products of combustion are cooled, to get GCV of the fuel.

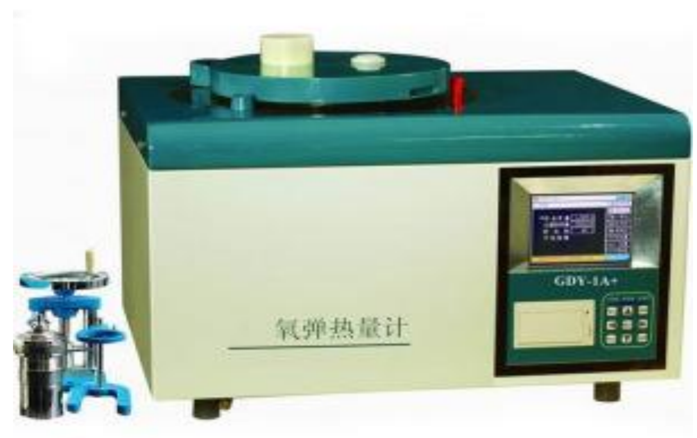
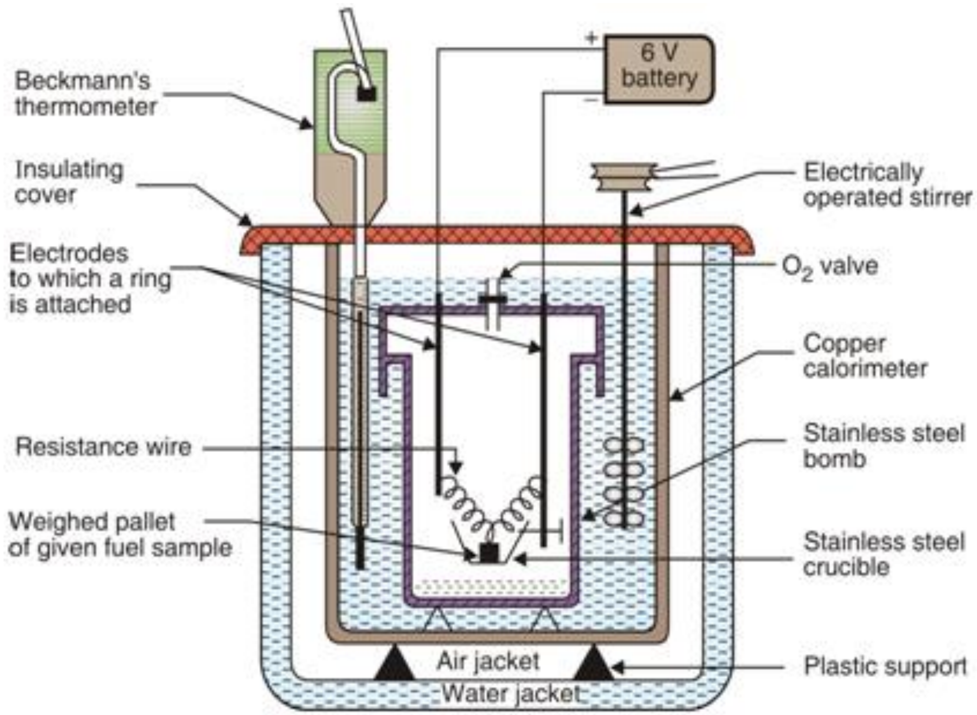


Diagram of Bomb Calorimeter



Corrections in GCV

a) Fuse Wire Correction

- Heat liberated during Ignition of Fuse wire need to be subtracted

b) Acid correction : Formation of acid is an Exothermic reaction and hence need to be subtracted from GCV to get exact GCV

$$S + O_2 \rightarrow SO_2$$

$$2SO_2 + O_2 + 2H_2O \rightarrow 2H_2SO_4 \quad \Delta H = -6.03 \times 10^5 \text{ J}$$

$$2N_2 + 2H_2O + 5O_2 \rightarrow 4HNO_3 \quad \Delta H = -2.39 \times 10^5 \text{ J}$$

Calculation of GCV

C) Cooling correction: (dt.t) is added in GCV

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

$$GCV = \frac{(W + w)(t_2 - t_1)}{x}\ cal/gm$$

$$corrected\ GCV = \frac{(W+w)(t_2-t_1+t_c)-(a+f)}{x}\ cal/gm$$

Numericals

1) The coal containing 5% hydrogen (dry / moisture free basis) and 10% moisture has gross calorific value of 33.5 MJ/kg. Calculate Net Calorific Value of Coal. Latent heat of water vapour is 2.45 MJ/kg.

2) 0.72 g of a fuel containing 80% Carbon, when burnt in a bomb calorimeter, increased the temperature of water from 27.3°C to 29.1°C. If the calorimeter contains 250 g of water and its water equivalent is 150 g, calculate GCV of the fuel.

Numericals

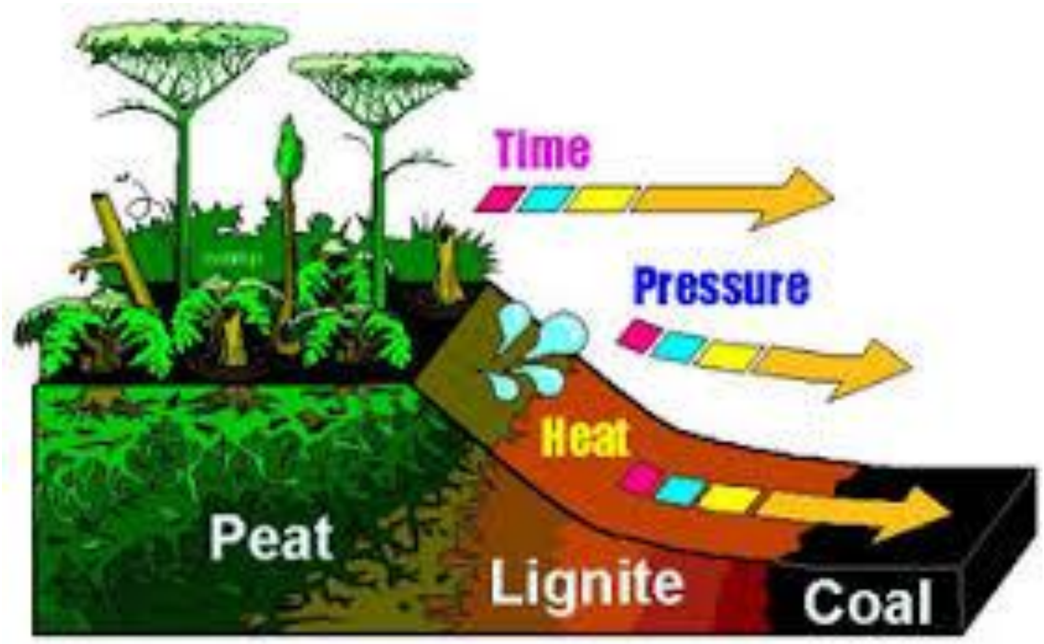
3) The temperature of 950.0 g of water increased from 25.5 ^{0}C to 28.5 ^{0}C. On burning, 0.75 g of solid fuel in a Bomb calorimeter. Water equivalent of copper calorimeter and latent heat of steam are 400 g and 587 cal/g respectively. If the fuel contains 0.65% of hydrogen, calculate net calorific value.

Numerical on GCV

4) A sample of coal containing 5% H when allowed to undergo combustion in Bomb Calorimeter, the following data were obtained

weight of coal burnt = 0.95 g
weight of water taken = 700 g
water equivalent of bomb calorimeter = 2000 g
rise in temperature = 2.48 °C
cooling correction = 0.02 °C
fuse wire correction = 10 cal
acid correction = 60 cal
Calculate Gross and Net Calorific Value of Coal.

COAL



https://www.youtube.com/watch?v=nIYz4Ck3w-k

Analysis of Coal

Proximate analysis

1. Moisture
2. Volatile Matter
3. Ash
4. % Fixed carbon

Ultimate analysis

a) Carbon
b) Hydrogen
c) Nitrogen
d) Sulphur
e) Oxygen

Proximate Analysis

Sr. No	Parameter	Apparatus used	Temperature	Exposure time
1)	Moisture	Hot air Oven	110 ^{0}C	1 hr
2)	Volatile Matter	Muffle Furnace	925 ^{0}C	7 minutes
3)	Ash	Muffle Furnace	750 ^{0}C	30 minutes

Proximate Analysis Calculation

$$Moisture(M) = \frac{m - m1}{m} \times 100$$

$$Volatile\ Matter\ (VM) = \frac{m1 - m2}{m} \times 100$$

$$VM\ (\%) = \frac{loss in\ wt.due\ to\ VM\ and\ M}{weight\ of\ coal} \times 100 - M\%$$

$$Ash = \frac{weight\ of\ ash}{weight\ of\ coal} \times 100$$

$$fixed\ Carbon\ (\%) = 100 - (\ M\% + VM\% + ash\%)$$

Significance of proximate analysis

- **Low moisture content indicates better quality of coal**
- **Low VM indicates better quality of coal**
- **Low ash content implies good quality coal**
- **Higher the carbon content indicate better the quality of coal.**

Numericals

1)1.508 g of coal sample was heated at 110 ^oC for 1h. On cooling the weight of the sample was found as 1.478 g. Strong heating of the sample at 950 ^oC for 7 min. carried out in a closed crucible. The sample on cooling weighed 1.058g. Calculate % moisture and % volatile matter present in the sample.

2) 1.2 g of coal sample heated at 105-110 ^oC for 1 h, after heating the sample weighed 1.16 g. This remaining sample of coal ignited at constant weight of 0.09 g. In another experiment, 1.2 g of sample was heated in a crucible at 950 ^oC for 7 min. After cooling the residue weighed 0.8 g. Calculate % of fixed carbon

Lecture 4

Ultimate Analysis

1) Estimation of Carbon and hydrogen

2) Estimation of nitrogen

3) Estimation of Sulphur

Numericals

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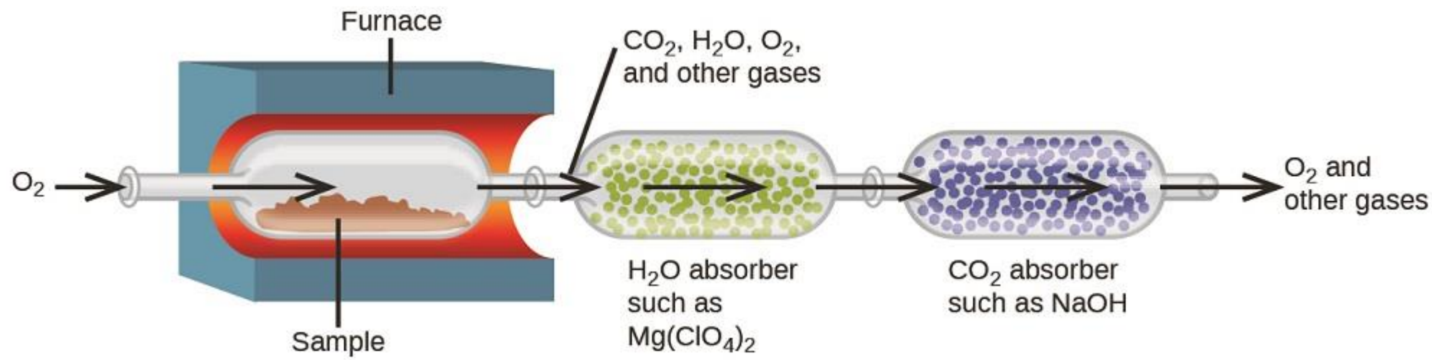
Ultimate Analysis of Coal

- Quantitative analysis involving estimation of Elements in coal
- Carbon on combustion get converted into CO_2
- Hydrogen on Combustion get Converted into H_2O
- Amount of carbon and hydrogen in coal is analyzed in terms of CO_2 and H_2O respectively

Ultimate Analysis



$$\underset{(12)}{C} + O_2 \longrightarrow \underset{(44)}{CO_2}$$

$$\underset{(2)}{H_2} + \tfrac{1}{2} O_2 \longrightarrow \underset{(18)}{H_2O}$$

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Ultimate Analysis

$$Carbon\ (\%) = \frac{12}{44} \times \frac{Increase\ in\ weight\ of\ KOH\ tube}{Weight\ of\ coal} \times 100$$

$$Hydrogen\ (\%) = \frac{2}{18} \times \frac{Increase\ in\ weight\ of\ CaCl2\ Tube}{Weight\ of\ coal} \times 100$$

Nitrogen Estimation

- Conversion of Nitrogen into Ammonium sulphate
- Ammonium sulphate get transform into NH_3 by treatment with NaOH
- NH_3 is absorbed in standard acid solution
- Difference in Blank and Back titration gives the amount of acid consumed by NH_3

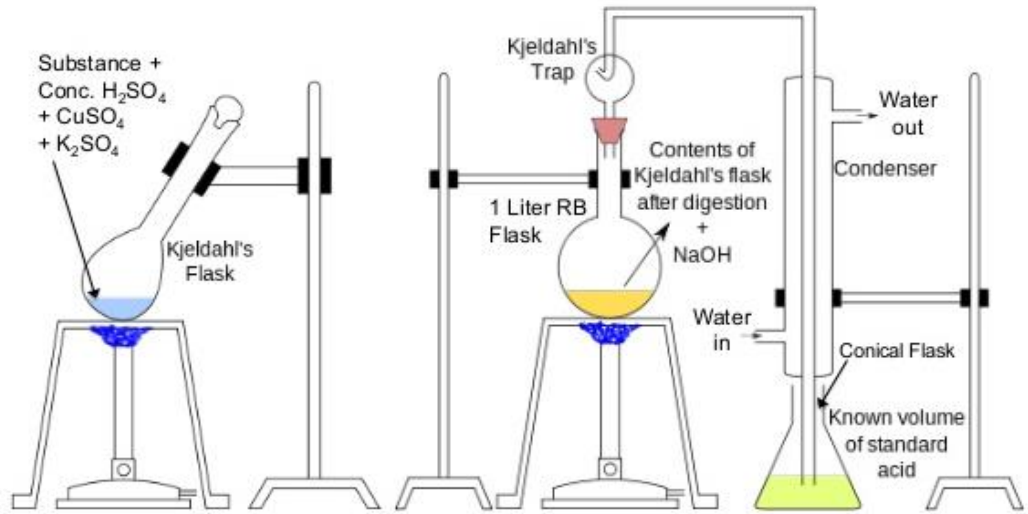


Image: Wikipedia

$$Nitrogen\,(\%) = \frac{(v2 - v1) \times N \times 1.4}{weight\ of\ coal}$$

Sulfur Estimation

- determined From washing obtained from known mass of coal used in bomb calorimeter for determination of CV
- Washings are treated with $BaCl_2$ forming $BaSO_4$

$$\text{Sulfur}(\%) = \frac{32}{233} \times \frac{\text{weight of BaSO4 (ppt)}}{\text{weight of coal}} \times 100$$

$$S \longrightarrow SO_2 \longrightarrow SO_3 \longrightarrow H_2SO_4$$

$$H_2SO_4 \downarrow BaSO_4$$

Significance of Ultimate Analysis

- High Percentage of C & H indicates good quality coal and high CV
- Nitrogen presence is undesirable
- Sulfur on combustion may cause acid formation leading to corrosion of equipment
- High Oxygen content decreases CV of coal

Numericals

1) 0.25 g of a coal sample on burning in a combustion chamber in the current of pure oxygen was found to increase weight of U-tube with anhydrous $CaCl_2$ by 0.075 g and of KOH U-tube by 0.52gm. Find C and H percentages in coal.

2) Find the % of C and H in coal sample from the following data- 0.20 g of coal on burning in a combustion tube in presence of pure oxygen was found to increase in the weight of $CaCl_2$ tube by 0.08 g and KOH tube by 0.12 g.

Lecture 5

- Petroleum
- Classification of petroleum
- Refining of petroleum
- Knocking
- Octane Number of petrol
- Cetane number of diesel

Liquid Fuels -Petroleum

Petroleum is a naturally occurring substance consisting of organic compounds in the form of gas, liquid, or semisolid. Organic compounds are carbon molecules that are bound to hydrogen (e.g., hydrocarbons) and to a lesser extent sulphur, oxygen, or nitrogen.

Classification of petroleum

three types :

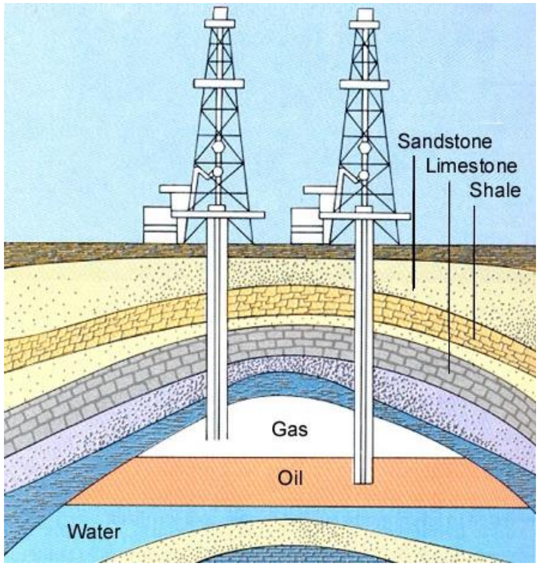
1) Paraffinic base type: Saturated hydrocarbons from CH_4 to $C_{35}H_{72}$

2) Asphaltic base type: Cycloparaffins with little amount of paraffins and aromatic hydrocarbons

3) Mixed base type: Both paraffinic and asphaltic hydrocarbons

Refining of Petroleum

- **Removal of water**
- **Removal of sulphur**
- **Fractional Distillation**

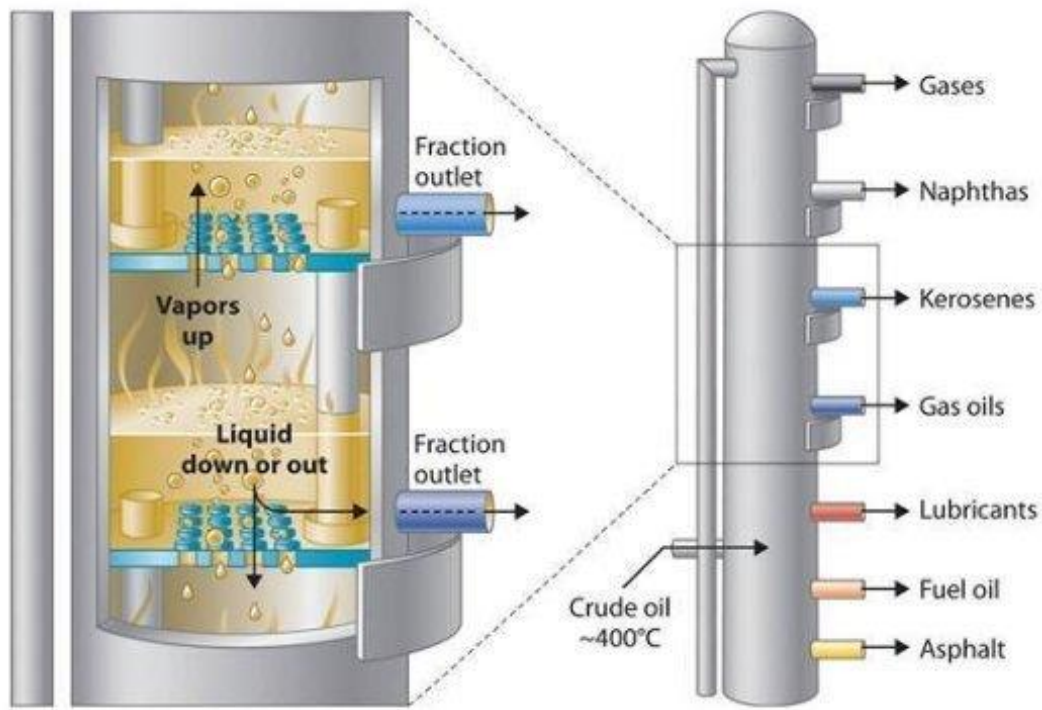


- https://www.youtube.com/watch?v=J2-tDV8KYEA&t=30s

Fractional Distillation of Petroleum

Principle of Fractional Distillation

Separation of a liquid mixture into fractions differing in boiling point (and hence chemical composition) by means of distillation, typically using a fractionating column.



Various fractions of crude oil

Name of Fraction	Chemical Composition	Boiling Range	Uses
Uncondensed Gases	C_1- C_4	Below 40 ^{0}C	Domestic fuel
Petroleum ether	C_5- C_7	40 ^{0}C – 70 ^{0}C	Solvent
Petrol	C_5-C_8	60 ^{0}C – 120 ^{0}C	Fuel for SI engine
Naptha	C_7-C_{10}	120 ^{0}C – 180 ^{0}C	Solvent
Kerosene	C_{10} –C_{16}	180 ^{0}C -250 ^{0}C	Domestic fuel
Diesel	C_{15} – C_{18}	250 ^{0}C – 320 ^{0}C	Fuel for CI Engine
Heavy Oil	C_{17} - C_{30}	320 ^{0}C- 400^{0}C	For making petrol by Cracking
Residue	above C_{30}	Above 400 ^{0}C	As Fuel and in rod making

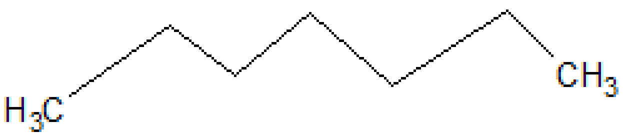
Octane Number

- indicator of fuel for its ability to resist knocking
- High octane number fuels have least tendency to undergo auto ignition
- n-heptane has zero octane number whereas isooctane has 100

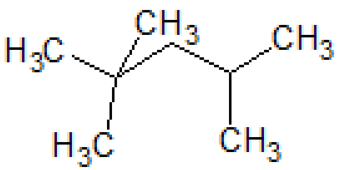
https://www.youtube.com/watch?v=uWx1cXR7x_M

Octane Number

Less Branching



More Branching



Trends:

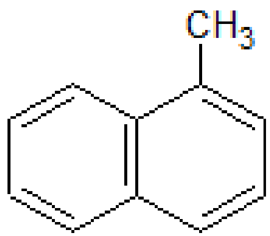
Aromatics > Cycloalkanes > Alkenes> Branched alkanes > Straight chain alkanes

Anti-knocking Agents

- Tetraethyl lead $Pb(C_2H_5)_4$ 0.5ml/litre
- Branched chain alkane of higher molecular weight
- Benzene, toluene, xylene
- Methyl t-butyl ether (MTBE) or ethyl t-butyl ether.

Cetane Number of Diesel

- Cetane number is the percentage by volume of n-cetane in mixture of n-cetane and 1- methyl napthalene which matches the fuel under testing condition



1- Methyl Napthalene

$CH_3\ (\ CH_2)_{14}CH_3$
n-Cetane

Improvement in Cetane Number

- Alkyl nitrates (principally 2-ethylhexyl nitrate) and di-*tert*-butylperoxide are used as additives to raise the Cetane number
- Antioxidant to improve oxidation resistance during storage.
- Lubricity additives for lubrication of fuel injection system.

Trends:
n-alkanes > Cycloalkanes >Alkenes>Branched alkanes >Aromatics

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Lecture 6

- **Combustion**
- **Calculations**
- **Numericals**

Combustion

- Combustion is a high-temperature exothermic redox chemical reaction between a fuel (the reductant) and an oxidant, usually atmospheric oxygen.
- Substances always combine in definite proportions. These proportions are determined by their molecular masses.
- $C + O_2 \rightarrow CO_2$ (12:32:44)

Calculation of Air for Combustion

- 22.4 L of any gas at 0°C and 760 mm Hg pressure (STP) has a mass equal to its 1 mol.
- Air contain 21% of oxygen by volume and 23% of oxygen by mass.
- 28.94 g/mol is taken as molar mass of air.
- O_2 required for combustion = theoretical O_2 required - O_2 present in the fuel.

Combustion

- **For solid or Liquid fuels:**

$$Oxygen\ Quantity = \left(\frac{32}{12} \times C + 8H + S - O\right) Kg$$

$$Actual\ Air = \frac{O_2\ Quantity \times (100 + \%excess\ air)}{23}\ kg$$

•For Gaseous fuels

O_2 volume required = volume gas component in m^3 x volume of O_2 per volume of gas.

$$Air = \frac{\text{Volume of } O_2 \times (100 + \%excess\ air)}{21}$$

Numericals

1) A petrol sample contains 14% H and 86% carbon. Calculate the quantity of air required for complete combustion of 1 kg petrol.

2) Volumetric analysis of producer gas is, H_2 = 20 % CO = 22 % N_2 = 50 %, CH_4 = 2 % and CO_2 = 6 %. Find volume of air required for complete combustion of 1 m^3 of the gas.

Numericals

3) A gas has following composition by volume, H_2 = 20 %, CH_4 = 6%, CO = 18%, O_2 = 5%, N_2 = 43 %. If 25 % excess air is used. Find volume of air actually supplied per m^3 of the gas.

4) A gas has following composition by volume: H_2 = 20 %; CH_4 = 6% , CO = 22%, CO_2 = 44% O_2= 4% N_2 = 4%. Calculate the volume of air required for complete combustion of 1 m^3 of the fuel.

Numericals

5) A sample of coal requires 20% excess air for complete combustion. Calculate weight of air for 250 g of the coal, if its composition is C = 81%, H = 4%, N = 1.5%, S = 1.2%, O = 3%, ash = 9.35.

6) A gas used in internal combustion engine contains, H_2 = 45 %, CO = 15%, CH_4 =35%, N_2= 5 % Find the minimum quantity (volume) of air required per 1 m^3 of the gas for complete combustion.