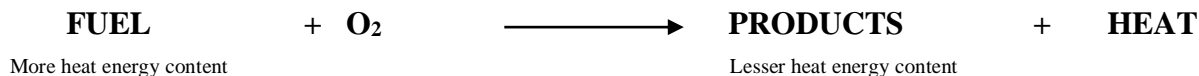**CHEMICAL FUELS**

FUEL:

A fuel is defined as **naturally occurring** or **artificially manufactured** combustible carbonaceous material which **serves** particularly as **source of heat and light** and also in few cases as a source of **raw material.**

FUEL   + O_2 ⟶   PRODUCTS   +   HEAT

More heat energy content   Lesser heat energy content

CLASSIFICATION OF CHEMICAL FUELS:-

Fuels are classified into a two types.

1) Based on their origin they are classified into

      a) Primary fuels

      b) Secondary fuels.

a) **PRIMARY FUELS:** These are **naturally occurring** fuels which serves as source of energy **without any chemical processing.**

  Ex: Wood, Coal, Crude oil, Natural gas, Peat, Lignite, Anthracite..

b) **SECONDARY FUELS: -** These are **derived** from primary fuels & serves as source of energy **only after subjecting to chemical processing.**

  Ex: Charcoal, Coke, producer gas, Petrol, Diesel etc.

2) Bases on their physical state fuel are classified into

      a) Solid fuels

      b) Liquid fuels

      c) Gaseous fuels

CLASSIFICATION OF FUELS	SOLID FUELS	LIQUID FUELS	GASEOUS FUELS
Primary Fuels	Wood, Coal ,Peat, Anthracite	Crude oil	Natural gas
Secondary Fuels	Coke, Charcoal	Petrol, Gasoline, Diesel	LPG, Producer gas, Coal gas, water gas, bio gas.

CALORIFIC VALUE :-

Calorific value is defined as the **amount of heat liberated** when a **unit mass of fuel** is burnt completely in presence of **air or oxygen.**

Calorific value is of two types as follows:-

1)   Higher calorific value. (HCV) or Gross calorific value. (GCV)

2)   Lower calorific value. (LCV) or Net calorific value. (NCV)

1) HCV (GCV): -

It is the **amount of heat liberated** when a **unit mass of fuel** burnt completely in the presence of air or oxygen and the **products of combustion are cooled to room temperature**. Here it includes the heat liberated during combustion and the latent heat of steam. Hence its value is always higher than lower calorific value. **HCV= Sensible heat + Latent heat of condensation of water** $GCV = \dfrac{(W+w) \times S \times \triangle t}{M}$ J /Kg

2) LCV (NCV): -

It is the **amount of heat liberated** when a **unit mass of fuel** is burnt completely in the presence of air or oxygen and **the product of combustion are letoff completely into air**. It does not include the latent heat of steam. Therefore it is always lesser than HCV.

NCV = GCV – Latent heat of steam.

NCV = GCV –0.09X % H_2 X 587 X 4.187 KJ/Kg

SI units of calorific value

In SI system the units of calorific values for solid fuels are expressed in KJ/Kg and for gaseous and liquid are expressed in KJ/m^3 at 1 atms. pressure and at 288K.

DETERMINATION OF CALORIFIC VALUE OF SOLID FUEL USING BOMB CALORIMETER:-

CONSTRUCTION:-

Bomb calorimeter consists of air tight sealed cylindrical **stainless steel bomb** in which combustion of fuel takes place. Bomb has a lid, which is provided with two **stainless steel electrodes** and an **oxygen inlet valve**. To one of the electrode, a small ring is attached. In this ring a **stainless steel crucible** can be supported. The bomb is placed in a **copper calorimeter**, which is surrounded by **air jacket** and **water jacket** to prevent heat losses due to radiation. The copper calorimeter is provided with a **mechanical stirrer** for dissipation of heat and a **Beckmann's thermometer** to read accurately the temperature rise.

WORKING:- A small quantity of a **fuel is weighed** accurately (M Kg) and is placed in the **Bomb**. The bomb is placed in **known amount water** taken in a copper calorimeter. The **initial temp** of water is noted as t_1^0C with the help of thermometer.

Oxygen gas is pumped under pressure 20 to 25 atm. through the O_2 valve provided. The fuel **is ignited** by passing **electric current** through the wires provided. As the fuel undergoes combustion and **liberates heat**, which is absorbed by surrounding water. The water is stirred continuously to distribute the heat uniformly and the **final temperature** attained by water is noted as t_2^0C & gross and net calorific value of the fuel is calculated as follows:-
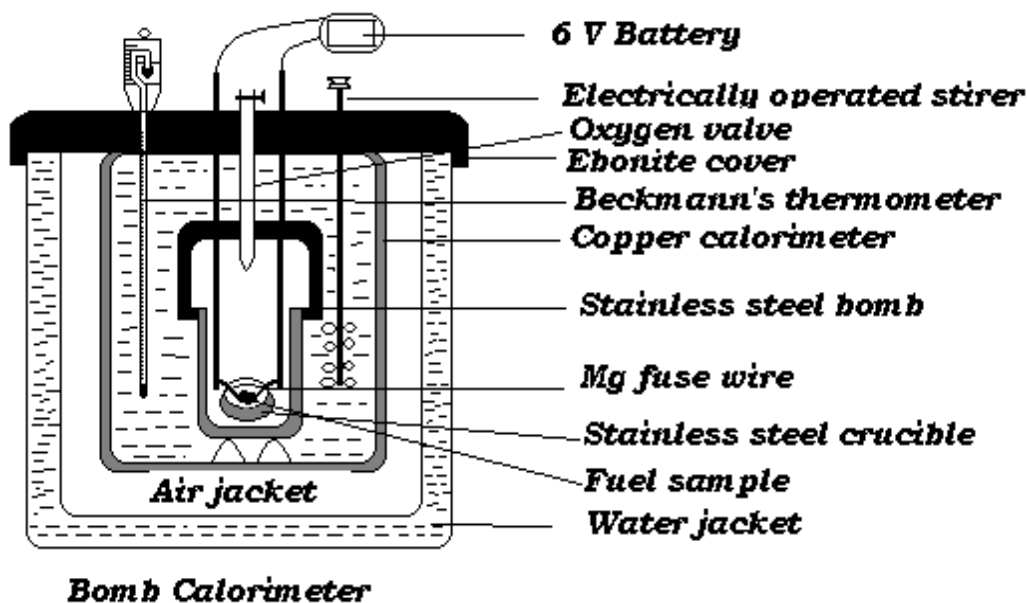
Bomb Calorimeter

Calculation:

Mass of the fuel = M Kg.
Weight of water taken in calorimeter=W Kg
Water equivalent of calorimeter = w Kg.
Specific heat of water = S J/Kg/^{0}C

Initial temp of the water = t_1^0C
Final temp of the water = t_2^0C
Change in temp = $\Delta t = (t_2 - t_1)^0$ C

$$GCV = \frac{W \times S \times \Delta t}{M} \text{ J/Kg} \qquad \textbf{OR} \qquad GCV = \frac{(W+w) \times S \times \Delta t}{M} \text{ J /Kg}$$

$$NCV = GCV - 0.09 \times \%H_2 \times 587 \times 4.187 J/g$$

1) Calculate calorific value coal samples from the following data.

Mass of the coal = 1g.   Water equivalent of calorimeter = 2 Kg.

Specific heat of water = 4.187 J/Kg/c.   Rise of temperature = 4.8^0C.

Solution: $GCV = \dfrac{(W+w) \times S \times \triangle t}{M} = \dfrac{2 \times 4.187 \times 4.8}{0.001}$

$$= \textbf{40195.2 KJ/Kg.}$$

2) A coal sample with 93% carbon, 5% of Hydrogen and 2% Ash is subjected to combustion in a bomb calorimeter. Calculate GCV and NCV Given that.

Mass of the coal sample = 0.95g   Mass of water in copper calorimeter = 2000g.

Water equivalent wt of calorimeter = 700g.   Rise in temp = 2.8^0C

Latent heat of = 587 cal/g.   Specific heat of water = 1 cal/g/^{0}C

Solution: $GCV = \dfrac{(W+w) \times S \times \triangle t}{M} = \dfrac{(2000+700) \times 10^{-3} \text{ kg} \times 1 \text{ cal/g/}^0C \times 2.8^0C \times 4.184}{0.95 \times 10^{-3} \text{ kg}}$

$$= 33295.83 \text{ J/kg.}$$

NCV = GCV – 0.09 x %H$_2$ x 587x4.184   J/kg.

= 33295.83 J/kg – 0.09 x 5 x 587 x4.184   J/kg.

= **32190.62 J/kg**

3) When 0.84g of coal was burnt completely in Bomb calorimeter the increase in temp of 2655 grams of water was 1.85^0C if the water equivalent calorimeter is 156g Calculate GCV.

Solution: $GCV = \dfrac{(W+w) \times S \times \triangle t}{M} = \dfrac{(2655+156) \times 1.85 \times 10^{-3} \times 4.187}{0.84 \times 10^{-3}}$

$$= 25921.26 \text{ J/Kg}$$

4) Calculate GCV and NCV of a fuel from the following data.

Mass of fuel=0.75g, W=350g.   t =3.02^0C, Mass of water = 1150, % H$_2$=2.8.

Solution: $GCV = \dfrac{(W+w) \times S \times \triangle t}{M} = \dfrac{(1150+350) \times 10^{-3} \times 3.02 \times 4.184}{0.75 \times 10^{-3}}$

$$GCV = \textbf{25271. 36 KJ/Kg}$$

NCV   = GCV –0.09 x H x 587 x 4.184

= 25271.36 – 0.09 x 2.8 x 587 x 4.184

NCV   = **24652.44 KJ/Kg**

5) Calculate calorific value of a fuel sample of a coal form the following data. Mass of the coal is 0.6g. Water equivalent wt of calorimeter is 2200g. Specific value 4.187 Kg/KJ/C rise in temp. = 6.52^0C.

Solution: $GCV = \dfrac{(W+w) \times S \times \triangle t}{M} = \dfrac{(2200) \times 10^{-3} \times 4.184 \times 6.52}{0.6 \times 10^{-3}}$

$$= 100025.49 \textbf{ KJ/Kg.}$$

6) Calculate GCV and NCV of a fuel from the following data. Mass of fuel =0.83g, W=3500g. , W = 385 g, t1 =29.2^0C, t$_2$ = 26.5_0C, % H$_2$ = 0.7 and S = 4.2 kj/kg/c

Solution: $GCV = \dfrac{(W+w) \times S \times \triangle t}{M} = \dfrac{(3.5 + 0.385) \times (29.2 – 26.5) \times 4.2}{0.83 \times 10^{-3}}$

$$GCV = 53079.39 \text{ KJ/Kg}$$

NCV= GCV –0.09 x H x 587 x 4.184

= 53079.39 – 0.09 x 0.7 x 587 x 4.2

NCV= **52924.07   KJ/Kg**

OCTANE NUMBER:- (used to express the quality of petrol fuel)

Octane number is defined as the percentage of **isooctane** present in a standard mixture of **isooctane and n-heptane**, which knocks at the same compression ratio as the petrol being tested.

Isooctane is the branched chain hydrocarbon has least knocking rate, hence its octane number is arbitrarily fixed as 100. N-heptane a straight chain hydrocarbon has highest tendency to knock hence its octane number is fixed as zero. Octane number of petrol is 80 means it contains 80% by volume isooctane and 20% by volume n- heptane.

CETANE NUMBER:- (used to express the quality of diesel fuel)

It is defined as the percentage of **cetane** present in standard mixture of a **cetane and α-methylnaphthalene**, which knocks at the same compression ratio as the diesel fuel being tested. Cetane number of cetane (n-hexadecane, $C_{16}H_{34}$) has arbitrarily fixed as 100, while α-methylnaphthalene ($C_{10}H_7$-CH_3) has cetane number arbitrarily fixed as zero. Diesel fuels with cetane no.s of 70-80 are commonly used.

KNOCKING- MECHANISM AND ILL EFFECTS:-

Knocking: The **explosive combustion of petrol and air mixture** produces **shock waves** in I.C. engine due to an increase in the **compression ratio** beyond a certain value, which hit the walls of the cylinder and piston producing a **rattling sound**, is known as **knocking**.
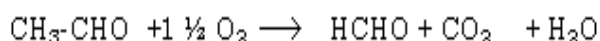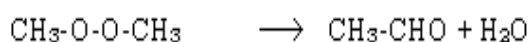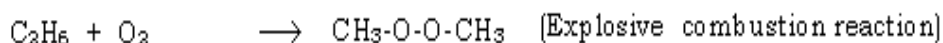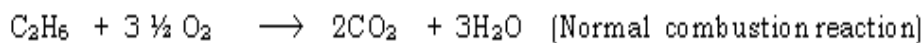
MECHANISM OF PETROL KNOCKING

The combustion is **initiated by a spark** in the cylinder. The flame thus produced spreads rapidly & smoothly through the gaseous mixture.

When petrol undergoes combustion under ideal conditions the **rate of flame propagation** is about **20-25 m/s**. there is a **slow oxidation** of the fuel during which oxygen combines with few hydrocarbon molecules & activates them. The activated molecule combines with the hydrocarbon molecules & a chain reaction is set up resulting in a **smooth combustion**.

Beyond a particular compression ratio the petrol mixture suddenly bursts into flame. The rate of flame propagation increases from **20 to 25 m/s to 2500 m/s**, which propagates very fast, producing a rattling sound. The hydrocarbon molecule combines with oxygen to **form peroxides**. The activated peroxide molecules decomposes to give number of **gaseous products** which produces **thermal shock waves** which dissipates its energy by hitting the walls of the cylinder and piston causing a rattling sound which is known as knocking.

The reactions of **normal and explosive combustion** of fuel can be given as follows taking **ethane** as an example

$$C_2H_6 + 3\tfrac{1}{2}O_2 \longrightarrow 2CO_2 + 3H_2O \quad \text{(Normal combustion reaction)}$$

$$C_2H_6 + O_2 \longrightarrow CH_3\text{-O-O-}CH_3 \quad \text{(Explosive combustion reaction)}$$

$$CH_3\text{-O-O-}CH_3 \longrightarrow CH_3\text{-CHO} + H_2O$$

$$CH_3\text{-CHO} + 1\tfrac{1}{2}O_2 \longrightarrow HCHO + CO_2 + H_2O$$

$$HCHO + O_2 \longrightarrow CO_2 + H_2O$$

Ill effects of knocking-

➢ It increases fuel consumption
➢ It decreases power output
➢ It reduces the efficiency and life of the engine
➢ It produces undesirable rattling noise
➢ It causes mechanical damage due to overheating, to engine parts such as piston, spark plug and engine walls
➢ The driving becomes rather unpleasant

PREVENTION OF KNOCKING: The knocking menace in IC engines can be controlled,
1. By using high octane rating gasoline.
2. By using critical compression ratio.
3. Modification in design of IC engine.
4. By using anti-knocking agents like TEL, TML, MTBE, ETBE, etc.,

[NOTE: DIESEL KNOCKING AND THEIR MECHANISM**:**
   Diesel engines work on the principle of **compression ignition**. Where fuel is exploded **not** by a **spark**, but by the application of **heat and pressure**. Air is drawn in to the cylinder and compressed to a pressure of about $3.5 \times 10^5 kg/m^2$. During compression cylinder gets **heated up to about 350^{0}C**. Then diesel is introduced in the form of a **spray** which spontaneously gets ignited and burns producing pressure on the piston. It takes some time for the fuel to get ignited. **The time interval between the fuel injection and ignition is called ignition delay**. It will be in milli seconds. The **shorter ignition delay** leads to burning of the fuel **at the rate at which it is injected**. **Longer ignition delay** results in **accumulation** of the fuel in the engine and this causes an **explosive combustion** when ignited. As a result the diesel engines knock.]

ANTIKNOCKING AGENTS
   The substances that are added to petrol in order to prevent knocking in I.C. Engines are called as antiknocking agents.
Ex: TEL   → Tetra Ethyl lead
       TML   → Tetra Methyl lead
       MTBE → Methyl Tertiary Butyl Ether
       ETBE → Ethyl Tertiary Butyl Ether

Leaded Petrol:
   The petrol containing TEL or TML as antiknocking agents is called **Leaded petrol**. TEL is an **extensively used antiknocking agent**. Tetra ethyl lead is added in the form of **ethyl fluid** which contains 63% TEL, 26% dibromoethane and 9% dichloroethane. TEL forms **Pb and PbO** which act as **free radical chain inhibitors** and thus curtail the propagation of explosive chain reaction and minimize knocking. TEL or TML are the very good anti knocking agents but has some disadvantages as follows.
   a) After combustion lead is deposited as lead oxide on piston and engine walls it leads to mechanical damage.
   b) Lead is a poisonous air pollutant.
   c) It spoils the catalyst used in catalytic converter.

Unleaded Petrol:
   The petrol whose **octane no. is increased** by the addition of substances **other than lead compounds** is referred to as **unleaded petrol** or the petrol which **does not contain any lead compound** is called unleaded petrol.
   In unleaded petrol, the octane value is increased by adding MTBE or ETBE. MTBE contains oxygen in form of ether group and supplies oxygen for the complete combustion of the petrol in IC engines, thereby reducing the formation of peroxy compounds.

Advantages of unleaded petrol
1. It is free from lead content
2. It can be used in modern vehicles fitted with catalytic convertor
3. It does not account for environmental pollution

POWER ALCOHOL:-

A **mixture of ethyl alcohol and gasoline blend**, which can be used as fuel in internal combustion engine, is known as **power alcohol or gasohol**. Due to lack of non-renewable fossil fuels gave stimulus to the production of ethyl alcohol from renewable plant sources. The main objective of using power alcohol are to reduce oil imports and provide an alternative to non-renewable energy source.
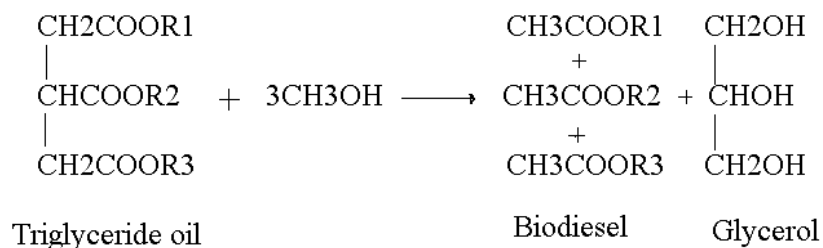
Ethanol is used as a fuel as Gasohol, a blend containing 10-85% ethanol and 90-15% gasoline (petrol) by volume. Absolute alcohol is mixed with ether, benzene etc compounds and **one volume** of **alcohol** is mixed with **four volumes** of **petrol** (**1:4 ratio resp.**) and is used as a fuel.

Advantages of Power Alcohol:

➢ The **power out put** is good.

➢ It has better **antiknock** property.

➢ Ethanol is **biodegradable**; hence it is environmental friendly fuel.

➢ The use of ethanol in power alcohol **increases the oxygen content** of the fuels and promotes more and complete combustion of hydrocarbons in gasoline.

➢ It reduces **carbon monoxide** emission.

BIODIESEL:-

➢ It is a **source of energy** obtained from **renewable sources of plant origin**. It can be used as an **alternative fuel to diesel** in automobiles and for **domestic commercial boilers**.

➢ Biodiesel refers to a **vegetable oil** or **animal fat** based diesel fuel consisting of a **long chain alkyl** (methyl, ethyl or propyl) **esters.**

➢ It is produced from vegetable oils such as soybean, jatropha, corn, sunflower, safflower, rapeseed, cotton seed, rice bran, rubber seed oil etc. using transestrification method. The used cooking oil, rendered animal fat and greases could also be converted into biodiesel.

➢ In this method oils, fats, waste vegetable oils and cooking oil are **heated with methanol** in the presence of NaOH. The resulting mixture of **monoalkyl esters of long chain fatty acid is referred to as biodiesel**.

$$
\begin{array}{ccc}
\underset{\text{Triglyceride oil}}{
\begin{array}{l}
CH2COOR1 \\
| \\
CHCOOR2 \\
| \\
CH2COOR3
\end{array}}
+ 3CH3OH \longrightarrow
\underset{\text{Biodiesel}}{
\begin{array}{l}
CH3COOR1 \\
+ \\
CH3COOR2 \\
+ \\
CH3COOR3
\end{array}}
+
\underset{\text{Glycerol}}{
\begin{array}{l}
CH2OH \\
| \\
CHOH \\
| \\
CH2OH
\end{array}}
\end{array}
$$

Where R_1, R_2 and R_3 are long chain fatty acid

Advantages of biodiesel:

i) It has higher cetane number compared to diesel.

ii) It is biodegradable

iii) It is made using renewable sources

iv) Less emission of harmful gases

v) It reduces greenhouse gases

vi) It is non-toxic

Fuel Cells

1. What are Fuel Cells?

A galvanic cell in which the electrical energy is directly derived by the combustion of chemical fuels supplied continuously.

2. Difference between conventional cell and fuel cell?

	BATTERY	FUEL CELL
1	Energy storage devices	Energy conversion devices.
2	Secondary Batteries are rechargeable	Fuel cells are not rechargeable.
3	Need Charging	Do not need charging
4	These store chemical energy	These don't store chemical energy
5	Reactants and products are not be supplied or removed respectively.	Reactants are supplied continuously and Products are removed constantly.
6	Reactants are a part of cell	The reactants (fuel & oxidant) are not a part of cell. They are supplied from outside.
7	Less efficient operation.	More efficient operation.
8	Less eco-friendly	More eco-friendly

3. Limitation and advantages of fuel cells:

Limitation of fuel cells

1. Fuel cells produce energy only as long as fuels and oxidants are supplied
2. The electrode used is costly.
3. Power output is moderate.
4. Fuels in the form of gases and oxygen need to be stored in tanks under high pressure.

Advantages of fuel cells

The fuel cells have the following advantages.

1. They offer high energy conversions
2. Their power efficiency is high
3. They are eco-friendly since the products of the overall reactions are not toxic
4. They can produce direct currents for long periods at a low cost
5. Fuel cells are used as auxiliary power generators in space vehicles, car engines, domestic lighting and heating.

Classification of Fuel cells:

Fuel cells are classified into three types based on **temperature**, fuel and electrolyte.

- (i) Low Temperature fuel cells: which use water based electrolytes below 100 ^{0}C.
  Ex: alkaline fuel cells and methanol-oxygen fuel cell.
- (ii) Medium Temperature fuel cells (100-600 ^{0}C): which use molten salts
  Ex: phosphoric acid fuel cell (PAFC)
- (iii) High Temperature fuel cells (about 1000 ^{0}C): which use ceramic electrolytes
  Ex: Molten carbonate fuel cell (operates at 650 ^{0}C)
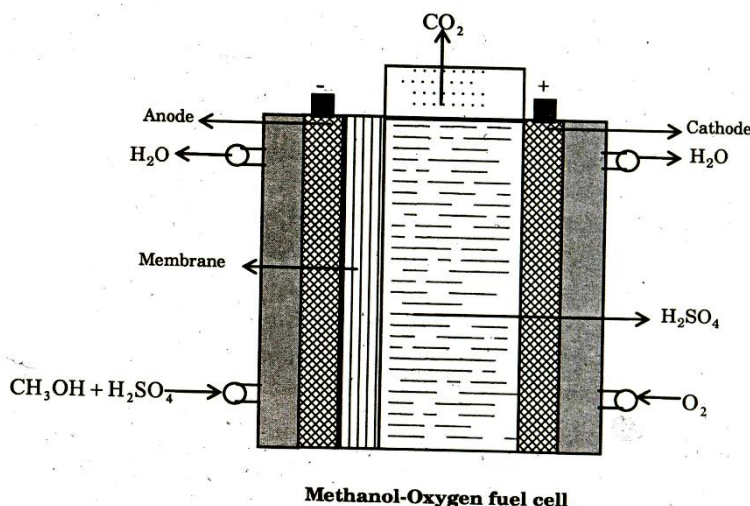 Solid Oxide fuel cell (operates above 1000 ^{0}C)

Based on the **electrolyte** the Fuel cells are classified into following types

- (i) Alkaline fuel cell: electrolyte used is KOH
- (ii) Phosphoric acid fuel cell: electrolyte used is conc. Phosphoric acid
- (iii) Molten carbonate fuel cell: electrolyte used is a mixture of alkaline carbonates of sodium and potassium
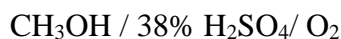- (iv) Solid-oxide Fuel cell: electrolyte used is solid ceramic generally consists of ZrO_2-Y_2O_3

Construction, working and applications of Methanol – Oxygen fuel cell.

Methanol – Oxygen fuel cell is an example for low temperature fuel cells which use water based electrolytes below 100 ^{0}C.
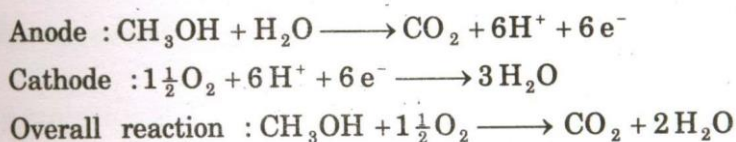
Methanol – Oxygen fuel cell consists of two electrodes made up of platinum. Methanol mixed with sulphuric acid (3.7M) is circulated through the anode chamber. Pure oxygen is passed through the cathode chamber and sulphuric acid (electrolyte) is placed in the central compartment. A membrane is inserted close to the cathode to minimize diffusion of methanol into the cathode thereby reducing the concentration of methanol near the cathode. In the absence of a membrane, methanol diffuses through the electrolyte into the cathode and undergoes oxidation. The methanol is oxidized to CO_2 & H_2O with the liberation of electrical energy. The cell delivers an EMF of 1.21V at 25 ^{0}C.

Methanol-Oxygen fuel cell

<u>**Cell Representation**</u>

$$CH_3OH \: / \: 38\% \: H_2SO_4 / \: O_2$$

<u>Cell Reactions</u>

$$\text{Anode} : CH_3OH + H_2O \longrightarrow CO_2 + 6H^+ + 6\,e^-$$
$$\text{Cathode} : 1\tfrac{1}{2}O_2 + 6\,H^+ + 6\,e^- \longrightarrow 3\,H_2O$$
$$\text{Overall reaction} : CH_3OH + 1\tfrac{1}{2}O_2 \longrightarrow CO_2 + 2\,H_2O$$

The advantage of acid electrolyte is that the CO_2, a product of the reaction, can be easily removed.

Applications of Methanol – Oxygen fuel cell
1) Used in Military applications.
2) Used for large scale power production stations.

Construction, working and applications of Solid oxide fuel cell (SOFCs)

Solid oxide fuel cell system usually utilizes a solid ceramic as the electrolyte and operates at extremely high temperatures (600-1000 ^{0}C).

Solid oxide fuel cell consists of three bonded layers, i.e., an anode, a cathode and solid oxide electrolyte separating the electrodes. Each electrode is thin, porous, electronic conductor. Porous electrode is required for gaseous diffusion between the electrodes outer surface and the electrode/electrolyte interface.

Anode: is a porous composite made of Nickel on ZrO_2 (Ni-Zirconia cermet); i.e, A mixture of nickel and yttria stabilized zirconia (YSZ) skeleton. Nickel plays the role as electrocatalyst for anode reaction whereas; the YSZ is used for conducting oxygen ions.

Cathode: is strontium-doped lanthanum manganite ($LaMnO_3$), because of its good electrochenmical activity for oxygen reduction, high electronic conductivity, good stability.
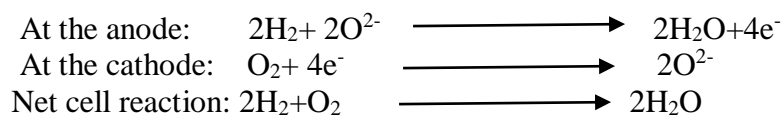
Electrolyte: The electrolyte used is a solid ceramic generally consists of ZrO_2-Y_2O_3; i.e., yttria stabilized zirconia (YSZ); or Zirconia doped with yttria. The electrolyte used is thin, fully dense oxygen ion conductor, but electrical insulator.
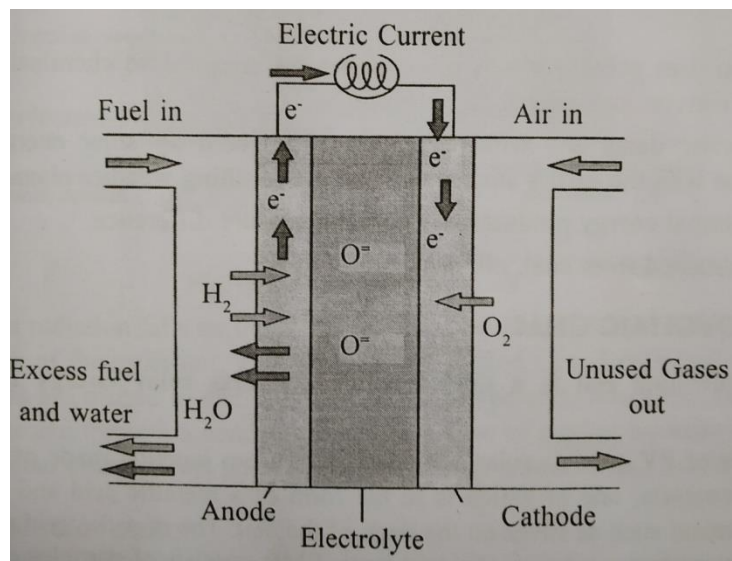
Figure: Solid oxide fuel cell

SOFCs use a solid oxide electrolyte to conduct negative oxygen ions (O^{2-}) from the cathode to the anode. The electrochemical oxidation of oxygen ions with hydrogen (H_2) or carbon monoxide (CO) thus occurs on the anode side. The advantage of using a solid electrolyte is that the system is less corrosive, more stable and safe than MCFC. No leakage occurs and the cell can be cast into multiple shapes.

The electrochemical reactions are:

At the anode: $\quad 2H_2 + 2O^{2-} \longrightarrow 2H_2O + 4e^-$

At the cathode: $\quad O_2 + 4e^- \longrightarrow 2O^{2-}$

Net cell reaction: $2H_2 + O_2 \longrightarrow 2H_2O$

Applications: SOFCs have a wide variety of applications as auxiliary power units in vehicles to stationary power generation with outputs from 100 W to 2MW. SOFCs produce large quantity of heat, therefore they are used in portable applications (like in laptops, cell phones etc), transportation applications, power distribution applications, space heating, water heating and in locomotives.

SOLAR ENERGY:

Introduction: Radiations from the sun constitute solar energy. Solar energy is freely available and is an inexaustive energy on which our entire planet is surviving. A few hours of solar energy falling on earth, if converted and utilized, will meet all the human requirements for one year.

The sun's radiation of wavelengths ranging from 100-1400 nm reaches the earth. Out of this, UV light, approximately 100-400 nm (UVA &UVB) is absorbed by the earth's atmosphere. About 45% of the total heat and light radiations (400-1400 nm) which fall in the visible and infrared region reaches the earth's surface. This energy is available for conversion into useful energy and is renewable and environmentally friendly for all species on our planet.

Solar Energy Utilization and Conversion

A wide range of power technologies exist which can make use of the solar energy reaching earth and converting them into different useful forms of energy. Solar energy utilization can be of two types - Direct solar power and indirect solar power.

Direct solar power:

Direct solar power involves only one step transformation into a usable form.

Examples:

- Sunlight hits photovoltaic cell (also called a photoelectric cell) generating electricity.
- Sunlight hits the dark absorber surface of a solar thermal collector and the surface warms. The heat energy may be carried away by a fluid circuit.
- Sunlight strikes a solar sail on a space craft and is converted directly into a force on the causes motion of the craft.

Indirect solar power :

Indirect solar power involves more than one transformation to reach a usable form.

Examples:

- Vegetation uses photosynthesis to convert solar energy to chemical energy, which can later be burnt as fuel to generate electricity (biofuel).
- Hydroelectric dams and wind turbines are powered by solar energy through its interaction with the Earth's atmosphere and the resulting weather phenomena.
- Ocean thermal energy production uses the thermal gradients that are present across ocean depths to generate power. These temperature differences are ultimately due to the energy of the sun.
- Energy obtained from oil, coal, and peat originated as solar energy captured by vegetation in the remote geological past and fossilized. Hence the term fossil fuel. The great time delay between the input of the solar energy and its recovery means these are not practically renewable and therefore not normally classified as solar power.

Advantages

- Solar power is relatively pollution free.
- Facilities can operate with little maintenance or intervention after initial setup.
- Solar power is becoming more and more economical as costs associated with production decreases, and the technology becomes more effective in energy conversion.
- Solar power can be viewed as a local resource because of regional climatic variances.
- Some countries, regions, etc (such as island communities, desolate regions and ocean-going vessels) are harvesting solar power as a viable energy resource than purchasing energy from other costly sources.

Disadvantages:

- It is only practical in certain areas with a favorable climate and latitude. That is, areas near the

tropics and which are relatively cloud free.

- It is not available at night and is reduced when there is cloud cover, decreasing the reliability of peak output performance.
- It must be converted into some other form of energy to be stored for times when conditions are prohibitive or to drive transport.
- Solar cell technologies produce DC power which must be converted to the AC power when used in distribution grids.

PHOTOVOLTAIC CELL - CONSTRUCTION AND WORKING

Definition: Photovoltaic cells or Solar cells are the **semiconductor devices which converts sunlight into direct current electricity**.

The Photovoltaic cells are made out of **semiconductors** which have the capacity **to absorb light**. A typical silicon photovoltaic cell is composed of a thin wafer consisting of an ultra thin layer of phosphorus doped (n-type) silicon on top of boron doped (p-type) silicon. Hence a **p-n junction** is formed. The **p-n junction** diode **separates and collects the carriers** and conducts the generated electrical current preferentially in a specific direction.

Construction: A solar cell consists of a p-n junction made of silicon. It has two electrical contacts, one of which is in the form of a metallic grid and the other is a layer of nobel metal such as silver on the back of the cell. The **metallic grid** allows light to fall on the semiconductor between the grid lines. **An antireflective layer between the grid lines increases the amount of light transmitted to the semiconductor**.

Sunlight consists of electromagnetic radiation of particles called **Photons** (hv). The photons carry a certain amount of energy given by the **Planck quantum equation,**

$$E = hc \,/\, \lambda$$

Where h is Planck's constant, c is the velocity of light and λ is the wavelength of the radiation.

Working: When electromagnetic radiation (sunlight) is incident normal to the plane of the solar cell, the photons, which possess energy sufficient to overcome the barrier potential are absorbed and electron- hole pairs are formed. This is shown in the figure. The **electrons are drifted to and collected at the n-type end** and the holes are drifted to p-type end. When these two ends are electrically connected through a conductor, there is a flow of current between the two ends through the external circuit. Thus photoelectric current is produced.
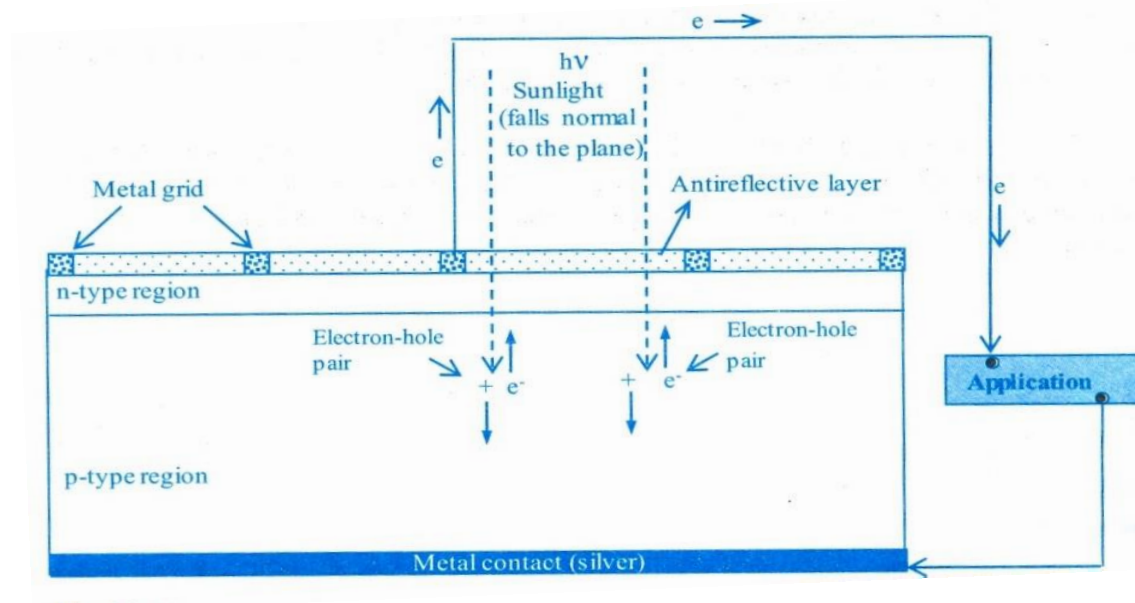

Figure: Photovoltaic (PV) cell

MODULES, PANELS AND ARRAYS

<u>Module:</u> A single solar cell produces only **0.5 volts** and hence cannot be used for power generation. **Atleast 36 cells** are connected **to form a module**. Thus module is the **basic building block of systems for power generation**. The cells in a module are connected in series provided with a **protective back surface**. This is called **encapsulation** and involves lamination of the cells between a **polymer and a thin film of aluminium or stainless steel** Encapsulation protects the module from **moisture and contaminants and pollutants** in the atmosphere and thus prevents failure of the solar module. Though this should produce **18** volts, it produces only **12 -14** volts because the cells get heated in the sun.
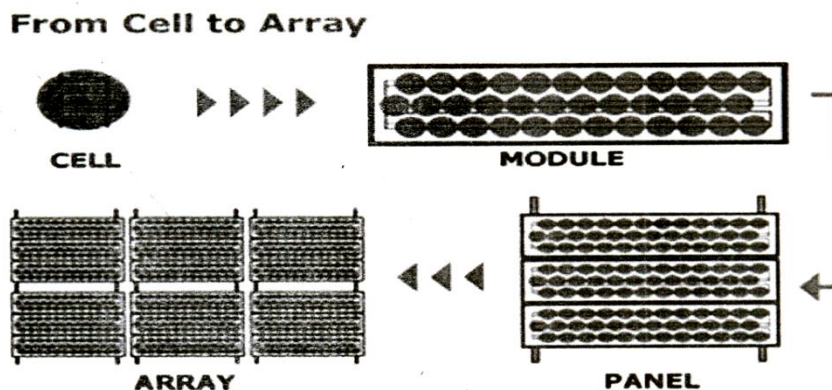
<u>Panel:</u> If higher energy is needed, the modules may be connected in series or in parallel The group of modules that are packaged and connected with wires for installation is called a **panel**. A set of **four or more modules are framed or attached together by struts in what is called a panel**. This panel is typically around **1.85 -3.25 square meter** in area for ease of handling on a roof.

<u>Array:</u> An array consists of **two or more panels and forms the power generating unit**. In a arrays, panels may be wired together in a series or parallel to deliver the voltage and current required for particular system.]]

Advantages of PV cells
The advantages of solar cells are given below.
- Make use of **renewable source of energy. ,** produce no pollution and therefore are environmentally friendly.
- Need **no recharging**.
- Have **no movable parts** and hence do not suffer from **wear and tear**.
- Operate at **ambient temperature**.
- Do **not corrode**.
- Use **renewable source of energy,** produce no pollution and therefore are environmentally friendly.
- **Quick** installation.

Disadvantages of PV cells
- Work only in **presence of sunlight**.
- **The efficiency** of solar cells depends on the **seasonal variations**, latitude and climate
- **Conversion efficiency per square meter** of the **panel** surface is around **14-19%.** A **30% efficient gallium arsenide or indium selenide** multi-junction cell are **expensive**.
- **Space is a constraint** that is space required to generate unit power out put is **relatively more**.
- **Dust often accumulates** on the panel thus reducing its efficiency.
- **High** installation **cost**.

PRODUCTION OF SOLAR GRADE SILICON: UNION CARBIDE PROCESS

The following steps are involved in the process:

Elemental silicon is made by the reduction of silica and carbon. Silica in the form of quartz and coke are placed in a crucible. Two carbon electrodes are placed in the crucible and an electric arc is struck. A high temperature is produced and silica is reduced to **elemental silicon**.

$$SiO_2 + 2C \xrightarrow{\text{1500 - 2000}°C} Si + 2CO$$

Molten Si obtained above is treated with air and fresh silica as a flux to remove the impurities Al, Mg and Ca.

$$4Al + 3SiO_2 \rightarrow 2Al_2O_3 + 3Si$$
$$2Mg + SiO_2 \rightarrow 2MgO + Si$$
$$2Ca + SiO_2 \rightarrow 2CaO + Si$$
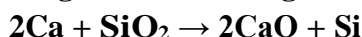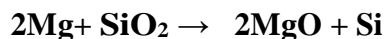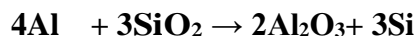
Oxides of Al, Mg and Ca form insoluble slag with excess of silica which is separated molten Si.

For example: $MgO + SiO_2 \rightarrow MgSiO_3$ **(slag of silicates)**

Silicon obtained after this step is called as **metallurgical grade Silicon** (98%).

To get semiconductor grade silicon the metallurgical grade silicon is treated with **dry HCl gas at 300°C** to obtain trichlorosilane and tetrachlorosilane.

$$Si + 3HCl \rightarrow \underset{\text{Trichlorosilane}}{HSiCl_3} + H_2$$

$$Si + 4HCl \rightarrow \underset{\text{Tetrachlorosilane}}{SiCl_4} + 2H_2$$

Trichlorosilane is removed by distillation and tetrachlorosilane is converted into trichlorosilane by **hydrogenating in a reactor at 1000°C.**

$$SiCl_4 + H_2 \rightarrow HSiCl_3 + HCl$$

Trichlorosilane is converted into silane by passing through **fixed bed columns containing quaternary ammonium ion exchange resin as catalyst**. Silane obtained in each step is removed by distillation.

$$2HSiCl_3 \rightarrow \underset{\text{Dichlorosilane}}{H_2SiCl_2} + SiCl_4$$

$$3H_2SiCl_2 \rightarrow \underset{\text{Silane}}{SiH_4} + 2HSiCl_3$$

Tetrachlorosilane and trichlorosilane obtained in the above steps are again passed through **hydrogenation reactor and fixed bed columns respectively** and finally converted to silane.
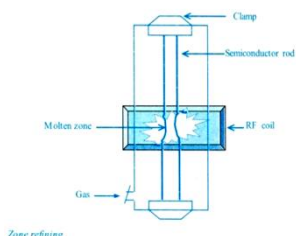
Silane obtained in the above step is subjected to **pyrolysis** in a reactor at high temperature. In **pyrolysis reactor**, pure Si rods are used for heating. Si formed by decomposition of silane gets deposited over these pure Si rods.

$$SiH_4 \longrightarrow Si + 2H_2$$
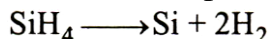
Si thus obtained can be further purified by zone refining.

[[**Note:**
PURIFICATION OF SILICON - ZONE REFINING

Silicon of 99.9999 purity can be obtained by zone refining. The principle of zone refining is that when a solid is melted, the impurities tend to concentrate in the molten zone.

A vertical zone refiner is used in the purification of silicon. A rod of silicon to be purified is clamped as shown in Fig. and is heated by a RF coil to the melting point of silicon in the presence of argon gas. The heater is moved very slowly from top to bottom. This is said to be *one zone pass*. Impurities move with the molten part of the material as the RF coil moves down. Pure silicon solidifies at the upper portion. When the process is complete, the bottom portion where the impurities are concentrated is removed. The rod is subjected to several zone passes to get ultrapure silicon.]]

****************Dr. SMP & Dr. MSS*************