MODULE 3

MODULE -3

ENERGY SYSTEMS

Chemical Fuels:

A combustible substance, which produces significant amount of heat and light energy when it is burnt in air or oxygen, is called a chemical fuel or fuel. The main constituents of fuel are carbon and hydrogen. When chemical fuel undergoes combustion in air, carbon and hydrogen are converted into carbon dioxide and water respectively.

$$\textbf{FUEL} + O_2 \longrightarrow \textbf{PRODUCTS} + \textbf{HEAT}$$

The primary or main sources of fuels are coal and petroleum oil. These are stored fuels available in earth's crust and are generally called fossil fuels.

Classification of fuels:

Depending on their origin fuels are classified into primary and secondary fuels.

Physical state	***Primary fuels***	***Secondary fuels***
Solid	Wood, coal, peat	Charcoal, coke.
Liquid	Petroleum (crude oil)	Petrol, kerosene, diesel oil
Gaseous	Natural gas	Producer gas($CO+N_2$), biogas,CNG water gas ($CO + H_2$), LPG

Calorific value: Calorific value of a fuel is "the amount of heat liberated, when a unit mass or volume of the fuel is burnt completely in air or oxygen".

Units: SI unit for solid fuels ***J/ kg***

For gaseous fuels ***J/m^3***

Gross(higher) calorific value(Q_{Gross}):

Q_{Gross} is the "the amount of heat produced, when unit mass/volume of the fuel has been burnt completely and the products of combustion have been cooled to room temperature".

On combustion carbon and hydrogen present in fuels are converted into carbon dioxide and steam respectively. On cooling the product steam gets condensed to water and liberates its latent heat. The measured gross calorific value includes the latent heat of steam. Therefore it is always higher than the net calorific value

Q_{Gross}= Sensible heat+ Latent heat of condensation of water.

Net (lower) calorific value (Q_{Net})

Q_{Net} is "the amount of heat produced, when unit mass/volume of the fuel is burnt completely and the products are permitted to escape or let off into the atmosphere".

The combustion products are let off into the atmosphere. Therefore this calorific value does not include the latent heat of steam. Net calorific value is always lower than gross calorific value.

Since 1 mole of H_2 (2g) liberates 1 mole of water (18g) the mass of water formed is nine times the mass of hydrogen in the fuel.

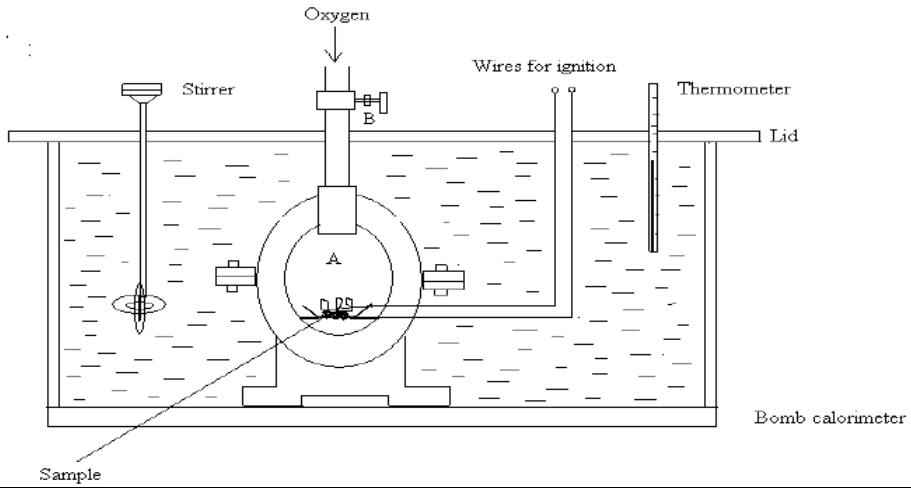
Net calorific value = Gross calorific value – latent heat of steam formed

= Gross calorific value – (Mass of $H_2 \times 9 \times$ latent heat of steam)

Net calorific value = Gross calorific value – (H_2 (in percent) $\times 0.09 \times$ latent heat of steam)

Note: Latent heat of steam = 587cal/g or 2454kJ/kg

Determination of calorific value of solid and liquid fuels using Bomb calorimeter



PRINCIPLE: A known weight of the sample (solid or liquid fuel) is burnt completely in excess of oxygen. Surrounding water and calorimeter absorbs the liberated heat. Thus the heat liberated during the combustion of fuel is equal to the heat absorbed by water and copper calorimeter.

CONSTRUCTION & WORKING

The calorific values of solid and liquid fuels can be determined by burning a known mass of the fuel in oxygen under high pressures. The bomb calorimeter consists of a strong cylindrical steel vessel A(bomb) with a capacity of 400-500ml. Oxygen is pumped at a pressure of 25-30 atmosphere A known mass of the fuel (about 1g) in the form of a pellet taken in a platinum crucible. The whole apparatus is placed in a weighed amount of water. The calorimeter is enclosed with a jacket to minimize heat exchange with the surroundings. The initial temperature of water is noted. The fuel is ignited through the electric current when rapid combustion of the fuel takes place. Water in the calorimeter is continuously stirred using an electric stirrer during heating. The maximum temperature attained by water is noted. The water equivalent of the calorimeter (w) is determined by burning a fuel of known calorific value.

CALCULATION:

Mass of the fuel= $\boldsymbol{m}$ kg

Weight of water taken in the calorimeter = $\boldsymbol{W}$g

Water equivalent of calorimeter = $\boldsymbol{w}$ k g

Initial temperature of water = $\boldsymbol{t_1}^0$C

Final temperature of water = $\boldsymbol{t_2}^0$C

Rise in temperature of water= $\Delta t = (t_2 - t_1)\ ^0$ C

Specific heat of water(S) = 4.187 kJ/kg

$$Q = \frac{(W+w) \times S \times \Delta t}{m} \quad J/kg$$

Net calorific value = GCV – latent heat of steam formed

= GCV – (0.09 × H% × latent heat of steam)

Gasoline (Petrol) Knocking and its Mechanism:

Definition:

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

An important method of obtaining more power from petrol is to increase the compression ratio of the engine. Compression ratio is the ratio of the initial volume of petrol air mixture which is sucked into the cylinder to the final volume after compression. Increase of compression ratio increases the efficiency of the engine and also saves the fuel. In IC engines the combustion reaction is initiated by a spark in the cylinder and under normal conditions the pressure inside the cylinder rises and slow oxidation of the fuel during which oxygen combines with a few hydrocarbon molecules and activates them. The rate of flame propagation is about 20-25 m/s and chain reaction proceeds in a smooth way. But beyond a particular compression ratio, the petrol–air mixture suddenly bursts into flames and the flame propagation rises to 2500m/s leading to explosive combustion. The chain reactions proceeds at a very fast rate, the hydrocarbons combine with oxygen to form peroxides. The unstable peroxides formed decompose readily to give a number of gaseous compounds. This give rise to shock waves which knocks the cylinder walls and piston. As a result a rattling sound is heard this is referred to as the knocking.

Illeffects

Knocking increases fuel consumption, driving becomes unpleasant, reduces engine power and damages the engine parts due to overheating of the cylindrical parts.

Prevention of knocking

In IC engines knocking can be prevented by

- Using high rating gasoline.
- Using critical compression ratio.
- Using anti knocking agents such as TEL, TML

***ANTI KNOCKING AGENTS*:**

Tetraethyl lead (TEL), tetramethyl lead and a mixture of TEL AND TML is used as anti-knocking agents. They are used along with ethylene dichloride or ethylene dibromide.TEL and TML get converted to Pb or PbO and get deposited on the engine parts or the exhaust pipe causing damages. But if they are used along with ethylene dichloride or dibromide, Pb and PbO are converted to volatile $PbCl_2$ or $PbBr_2$ that escape as gases into atmosphere.

UNLEADED PETROL: The petrol free from lead is called unleaded petrol. The octane rating enhancers such as methyl-t-butyl ether (MTBE), ethyl-t-butyl ether (ETBE), methanol, ethanol which have octane rating above 100, are added to unleaded petrol in place of TEL.One of the major advantages of unleaded petrol is the use of a catalytic converter attached to the exhaust in automobiles. Catalytic converter contains a rhodium catalyst which converts the toxic gases such as CO and NO to harmless CO_2 and N_2. However leaded petrol cannot be used in automobiles equipped with catalytic converter as the lead present in it poisons the catalyst.

POWER ALCOHOL (GASOHOL)

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. Blends containing 25% of alcohol with petrol is used.Industrial alcohol containing 95% alcohol and 5% of water can be mixed with petrol but by using some blending agent such as benzene, ether etc.

Advantages of alcohol blended petrol:

- Alcohol blended petrol possesses better anti-knocking properties.
- There is no starting difficulty with alcohol petrol blend.
- Air required for complete combustion is less.
- Reduces emission of Carbon monoxide and volatile organic compounds.

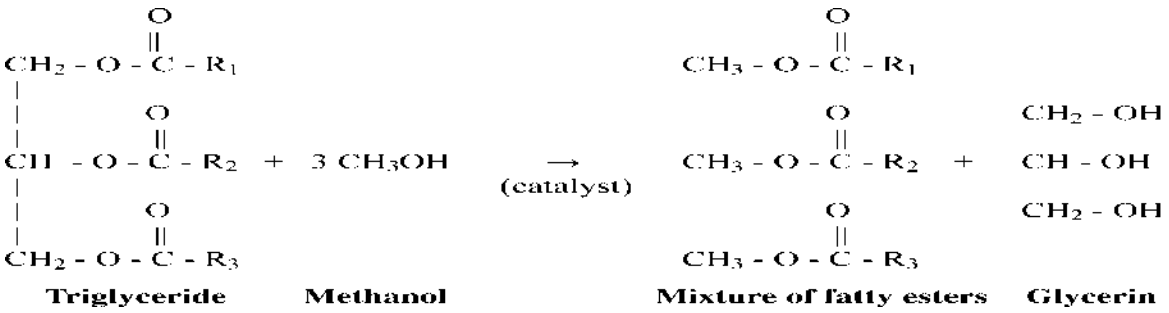
Disadvantages of alcohol blended petrol:

- Alcohol lowers the calorific value of petrol.
- Alcohol is easily oxidized to acids hence alcohol may cause corrosion.
- Alcohol absorbs moisture and as a result separation of alcohol and petrol layers takes place especially at low temperature. To avoid this, blending agents such as benzene or toluene are used.

Bio diesel:

Biodiesel is mixture of methyl or ethyl ester of fatty acid obtained from vegetable oil. It is obtained from vegetable oil such as soybean, linseed and jatropha. Biodiesel is synthesized by transesterification of triglyceride oil with methanol using NaOH as catalyst.

In this process triglyceride oil is treated with excess of methanol in presence of base. The products are a mixture of mono- methyl esters of long chain fatty acids and glycerin. The mixture is allowed to settle and the bottom glycerin layer is drawn off. The upper layer of methyl ester is washed and purified further to remove excess methanol. The mixture of methyl esters is called the biodiesel and has the desired characteristics of diesel fuel.



Advantages of Biodiesel

- Biodiesel is environmentally friendly.
- Biodiesel prolongs Engine Life.
- High Cetane number compared to diesel.
- Readily undergoes biodegradation.

Fuel cells

Fuel cell was introduced by William in 1839. *A fuel cell is a galvanic cell in which electrical energy is derived by combustion of fuel (Hydrogen, methanol, Natural gas) and a oxidant (Air or oxygen).* The fuel cell has two electrodes and an electrolyte. A fuel cell may be represented as

Fuel/electrode/electrolyte/electrode/oxidant

At the anode fuel undergoes oxidation and at the cathode oxidant undergoes reduction.

Fuel $\longrightarrow$ Oxidation product + ne^-

At the cathode, the oxidant gets reduced. ie Oxidant + ne^- $\longrightarrow$ Reduction product.

Difference between Battery(Conventional Cell) and Fuel Cells

Sl No:	Battery	Fuel cell
1.	*In a battery, the electrical energy is obtained as long as active materials are present.*	*In a fuel cell, the electrical energy is obtained continuously as long as reactants are supplied.*
2.	*Batteries store chemical energy.*	*Fuel cells do not store chemical energy.*
3.	*Reactants form an integral part of the battery.*	*Reactants are fed from outside the cell & do not form an integral part.*
4.	*Eg: Ni – MH battery.*	*Eg: Methanol – O_2 fuel cell*

Advantages

1. High efficiency
2. Silent operation
3. Ecofriendly since harmless products.
4. Produce dc at low cost

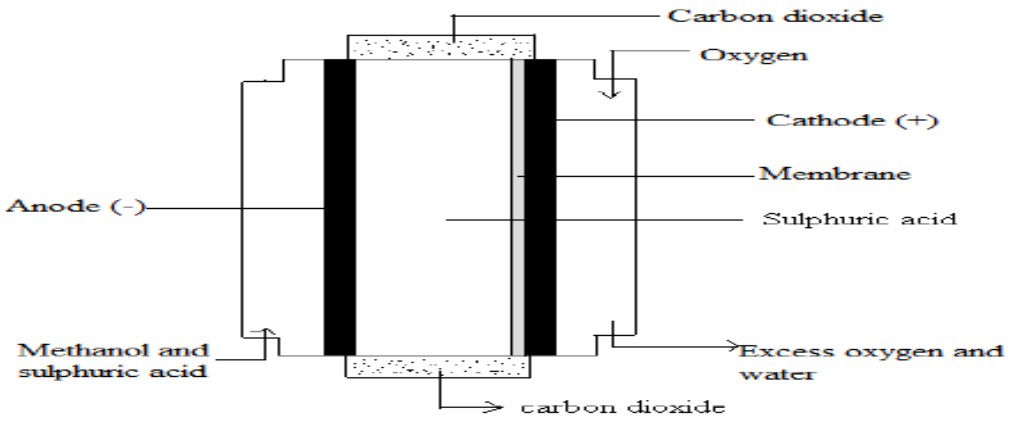
Limitations

1. High initial cost of the system (catalyst, membranes etc).
2. Fuel in form of gases and oxygen need to be stored in high pressure tanks

Methanol –Oxygen fuel cell

In Methanol-Oxygen fuel cell, methanol is used as fuel and oxygen as oxidant. Methanol containing some sulphuric acid (3.7M) is circulated through the anode chamber. Pure oxygen is passed through the cathode chamber and sulphuric acid (which is the electrolyte) is placed in the central compartment. Both the electrodes are made of platinum. A membrane is placed adjacent to the cathode on the inner side to minimize the 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 itself. The emf of the cell is 1.2V at 25°C.



The electrode reactions are,

At anode: $CH_3OH + H_2O \longrightarrow CO_2 + 6H^+ + 6\,e^-$

At cathode: $3/2\ O_2 + 6H^+ + 6\,e^- \longrightarrow 3\ H_2O$

Net cell reaction is: $CH_3OH + 3/2\ O_2 \longrightarrow CO_2 + H_2O$

Applications: ▸ It is used in military applications and in large scale power production.

Solid Oxide fuel cell

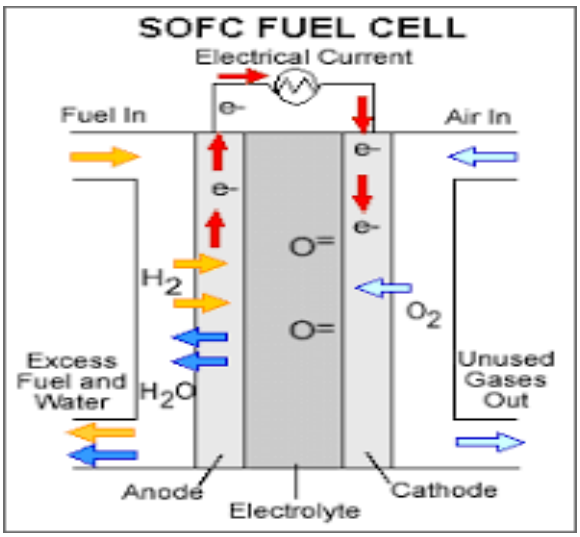
The anode is Ni-ZrO_2 cermet and the cathode is Sr doped $LaMnO_3$.Hydrogen is used as fuel and oxygen as oxidant. It uses a solid electrolyte (ZrO_2) and (Y_2O_3).The fuel cell operates at very high at temperature above 1000°C.Solid Oxide fuel cell produces electricity directly by oxidizing fuel using solid oxide as electrolyte. At cathode oxygen under reduction to form oxygen ion (Oxide ion) and at anode Oxide ions combines with hydrogen to form water with liberation of electron.

At Anode , $\mathbf{O^{2-} + H_2 \longrightarrow H_2O + 2e^-}$

At cathode , $\mathbf{½\ O_2 + 2e^- \longrightarrow O^{2-}}$

Overall Reaction, $\mathbf{H_2 + ½\ O_2 \longrightarrow H_2O}$

Uses: Lightening purposes and locomotives.



SOLAR ENERGY

Introduction: Energy is very essential to human being. The coal, petroleum, natural gases were basic forms of energy. But today all these forms are being slowly depleting from earth's surface. The world is looking for new form of energy such as solar energy, as gained lot of importance. Photovoltaic cells or solar cells are semiconductor devices they convert sunlight falling on them into direct electricity. As long as light falls on the solar cell it generates electrical power. When the light falling on the solar cell stops, generation of electricity stops.

Advantages of Solar cell.

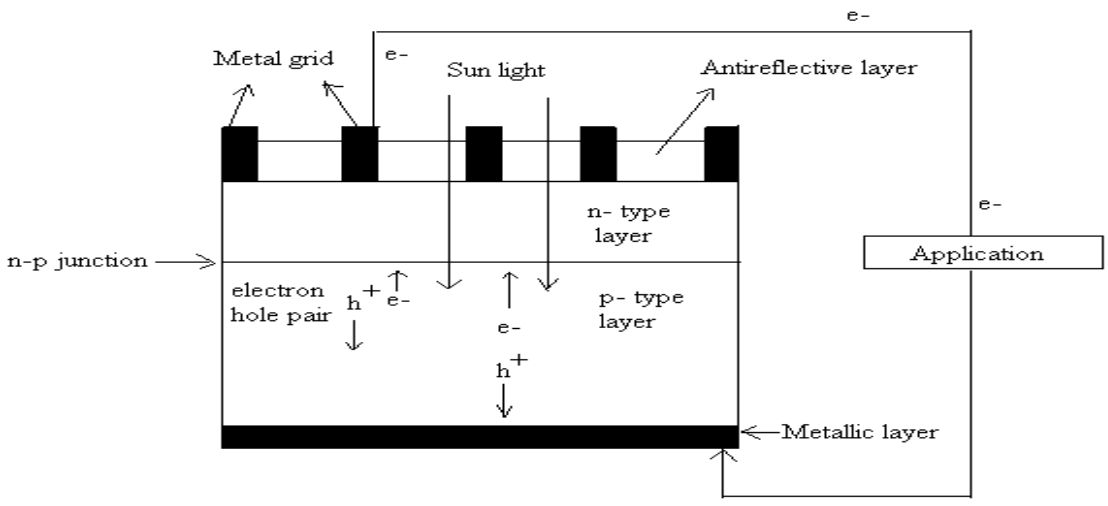
- Solar power is unlimited and inexhaustible and pollution free.
- They need no recharging
- They operate at ambient temperature.
- They do not corrode
- They are environment friendly.
- They have no movable parts and hence no wear and tear.

Disadvantages of Solar cell

- It is practically favorable near tropics (Sunny area) with relatively cloud free.
- It is not available at night.
- The main hindrance to solar energy going widespread is the cost of installing solar panels.
- Solar cells produce DC power which has to be converted into AC power when used into distribution grids.

Construction & Working of a Photovoltaic cell.

Photovoltaic cells is composed of thin matter of ultra thin layer of phosphorous doped (n- type) silicon on the top and boron doped (p-type) silicon. Hence p-n junction are brought together to form a metallurgical junction. The diode has two electrical contacts one of which is in the form of a metallic grid and other is a layer of noble metal on the back of the solar cell. The metallic grid allows light to fall on the semiconductor between the grid lines. An antireflective layer (Silicon nitride) is coated in between metal grids to prevent reflection of sunlight. When light radiation falls on the p-n junction diode, electron hole pairs are generated by the absorption of the radiation. The electrons are drifted to and collected at the n- type end and holes are drifted to and collected at the p-type end. When these two ends are electrically connected through a conductor, there is a flow of current between two ends through the external circuit. Thus photoelectric current is produced and available for use.



Solar cell grade silicon - Production by Union Carbide Process

i)Quartz (SiO_2) is reduced to Si using Coke in an electric furnace heated to a high temperature of 1500-2000^oC.

$$SiO_2 + 2C \longrightarrow Si + 2CO$$

ii)The silicon obtained is treated with oxygen and silica sand. The elements such as Al, Ca and Mg react with silica sand (SiO_2) to form slag and silicon. The silicon obtained is called metallurgical grade silicon (98%).

iii)The metallurgical grade silicon is treated with dry HCl gas at 300^oC to form trichlorosilane and small amount of tetrachlorosilane.

$$Si + 3\ HCl \longrightarrow HSiCl_3 + H_2$$

$$Si + 4\ HCl \longrightarrow SiCl_4 + 2H_2$$

The mixture is distilled to get pure trichlorosilane.

iv)The hydrogenation of tetrachlorosilane in a reactor at 1000^o C carried out in a fluidized bed reactor to give trichlorosilane.

$$SiCl_4 + 2H_2 \longrightarrow 4SiHCl_3$$

v) The purified trichlorosilane is passed through a fixed bed column filled with quaternary ammonium ion exchange resin catalyst. Trichlorosilane converts to dichlorosilane. The products are separated by distillation, Tetrachlorosilane is recycled to the hydrogenation reactor and dichlorosilane is passed through second bed column filled with quaternary ammonium ion exchange resin to give Silane.

$$2HSiCl_3 \longrightarrow H_2SiCl_2 + SiCl_4$$

$$3H_2SiCl_2 \longrightarrow SiH_4 + 2HSiCl_3$$

The above products are separated by distillation and trichlorosilane is recycled to the first fixed bed column.

vi) Silane is purified by distillation and pyrolized through heated silicon seed rods mounted in a metal bell jar reactor to produce Silicon.

$$SiH_4 \longrightarrow 2H_2 + Si$$

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1. What is gasoline (Petrol) knocking? Write the mechanism.

2. What is biodesiel.Explain preparation involved on it.

3. Discuss i) Power alcohol ii) Biodiesel

4. Explain construction, working of bomb Calorimeter.

5 Explain Gross and net calorific value

6. Write construction and working of methanol oxygen fuel cell.

7. Write construction and working of Solid Oxide fuel cell

8. Explain production of silicon by Union Carbide process

9. Explain construction & working of photovoltaic cell.

10. What is fuel cell? Write any four differences between battery and fuel cell. Mention any two limitation of fuel cell.

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PSK