Module-3

ENERGY SYSTEMS

Chemical Fuels: Introduction, classification, definitions of CV, LCV, and HCV, determination of calorific value of solid/liquid fuel using bomb calorimeter, numerical problems. Knocking of petrol engine – Definition, mechanism, ill effects and prevention. Power alcohol, unleaded petrol and Biodiesel.
Fuel Cells: Introduction, differences between conventional cell and fuel cell, limitations & advantages. Construction, working & applications of methanol-oxygen fuel cell with H_2SO_4 electrolyte, and solid oxide fuel cell (SOFCs).
Solar Energy: Photovoltaic cells- introduction, construction and working of a typical PV cell. Preparation of solar grade silicon by Union Carbide Process/Method. Advantages & disadvantages of PV cells.
(RBT Levels: L3)
Course outcome: Production & consumption of energy for industrialization of country and living standards of people. Electrochemical and concentration cells. Classical, modern batteries and fuel cells. Utilization of solar energy for different useful forms of energy.

Chemical Fuels

Fuel: Fuel is defined as naturally occurring or an artificially manufactured carbonaceous substance which serves as a source of heat and light.

Classification of fuels

1) Primary fuels: They are naturally occurring fuels

Ex: Solid – coal, wood, lignite, peat
Liquid – crude oil
Gas – biogas

2) Secondary fuels: They are derived from primary fuels

Ex: Solid – charcoal, coke, etc
Liquid – kerosene, diesel, synthetic petrol, benzene, etc
Gas – water gas, producer gas, LPG etc

Calorific value

"The amount of heat liberated by burning a known mass of fuel in presence of air" is called *calorific value*.

Gross calorific value or High calorific value (GCV or HCV):

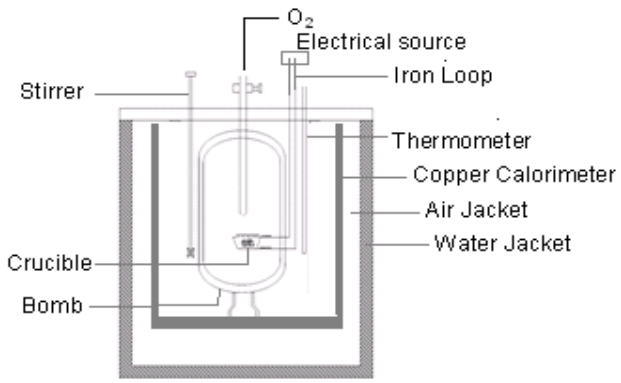
The amount of heat liberated when a unit mass of a fuel is burnt in excess air & the products of combustion are cooled to room temperature" is called *Gross Calorific Value*.

Net calorific value or Less calorific value (NCV or LCV):

The amount of heat liberated when a unit mass of a fuel is burnt in excess air and the product of combustion is allowed to escape in the atmosphere is called *Net Calorific Value*.

Net calorific value = Gross calorific value – Latent heat of steam of H_2O.

Determination of Calorific Value of fuel using Bomb Calorimeter



Construction: A bomb calorimeter consists of a cylindrical vessel fixed with inlet valve for pumping of O_2. A Ceramic or platinum crucible is placed at the bottom of the vessel connected with iron wire, the end of the wire is connected to battery. The bomb is than placed in known weight of H_2O taken in a copper calorimeter and enclosed in air & water jacket to prevent heat exchange with the surrounding. Electrical stirrer is placed one side to maintain uniform temperature and thermometer on the other side.

Working: A known weight of a fuel is taken in crucible Oxygen is pumped into a bomb at a pressure of 25-30 atm. Initial temperature of H_2O is noted. The fuel is ignited through spark produced by iron wire. The heat liberated is absorbed by surrounding water and calorimeter. The water in a jacket is continuously stirred. The maximum temperature attained by water is noted.

Principle: The amount of heat liberated by the fuel is equal to amount of heat absorbed by water and calorimeter.

Observation and calculation:

Let weight of fuel taken	= 'm' kg
Initial temperature of water	= T1° c
Final temperature of water	= T2° c
Change in temperature	= (T2-T1) = ΔT °c
Weight of water taken in calorimeter	= 'W' kg
Water equivalent of calorimeter	= 'w' kg
Specific heat of H2O	= 'S' J kg^{-1} c^{-1}

$$GCV = \frac{(W+w)\,kg \times S\,J\,kg^{-1}\,c^{-1} \times \Delta T°c}{m\,kg}$$

$$GCV = \frac{(W+w)\,S\Delta T}{m}\ J\,kg^{-1}$$

Knocking and its mechanism

It is the rattling sound being produced in an internal combustion engine due to the explosive combustion of fuel.

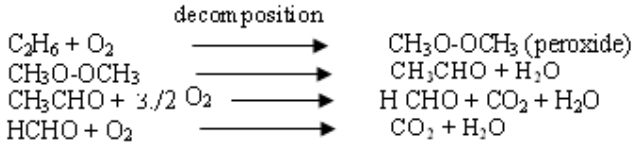
The efficiency of an IC engine depends on the *Compression ratio.*

$$\text{Compression ratio} = \frac{\text{Volume of cylinder at end of suction stroke}}{\text{Volume of cylinder at end of compression stroke}}$$

The petrol-air mixture drawn in the cylinder is compressed and ignited. Under ideal conditions (eg, CR-5 to10) the hydrocarbons undergo combustion and the flame propagates smoothly to produce power.

$$C_2H_4 + 7/2\ O_2 \longrightarrow 2CO_2 + 3H_2O$$

But, if the hydrocarbon present is unable to withstand pressure at high compression ratio (CR > 10), then hydrocarbons of the fuel combine directly with oxygen to form unstable peroxides which decompose and burst suddenly into flames by pre ignition producing shock waves. The shock wave hits the walls of the engine part producing sound. This is called as knocking. The knocking mechanism is as follows.



Ill effects of knocking: Decreases in life of engine, causes mechanical damage to engine parts such as spark plug, piston and engine walls, more consumption of fuel and power output decreases

Prevention of Knocking using anti-knocking agents

The substances that are added to gasoline in order to decrease the knocking tendency is called *"anti-knocking agents"*.

The commonly used anti-knocking agent is Tetra ethyl lead (TEL), usually 1-1.5 ml of TEL is added to petrol along with ethylene dichloride or ethylene di-bromide.

Unleaded Petrol: The gasoline in which the antiknocking properties are increased without addition of lead substance is called unleaded petrol. In orders to improve the octane number of unleaded petrol some compounds like methyl tertiary butyl ether (MTBE) is added.

Addition of MTBE: Methyl tertiary butyl ether (MTBE) added to petrol (unleaded petrol) provides oxygen for combustion, thereby reduces the formation of peroxy compounds. MTBE can be used as anti knocking agent in IC engines with catalytic converter.

Advantages of Unleaded petrol

1) It increases the efficiency of the engine.

It permits the attachment of catalytic converters to the exhaust pipe of automobiles. The catalytic converters convert toxic gases like carbon monoxide and nitric oxide to CO2 and N2.

Additional information

Leaded petrol: The Petrol containing Tetra ethyl lead (TEL). Tetraethyl Lead decomposes the peroxides formed and prevents knocking. In the process, lead gets deposited on the inner walls of the engines and at spark plugs. Hence ethylene di-chloride or ethylene di-bromide is added along with tetraethyl lead. These convert the lead into $PbCl_2$ or $PbBr_2$, which are volatile and escape with exhaust gases. The release of lead compounds pollutes the atmosphere.

TEL cannot be used as anti knocking agent in IC engines with catalytic converter.

Power alcohol

Power alcohol is alcohol petrol blend containing 25% of alcohol and 75% of petrol. It is used as fuel in internal combustion engine.

Advantages:

- Alcohol petrol blend processes better anti-knocking properties.
- Alcohol petrol blend can be used in an engine with higher compression ratio.
- There is no starting difficulty with alcohol petrol blend.
- Air required for the complete combustion is less.

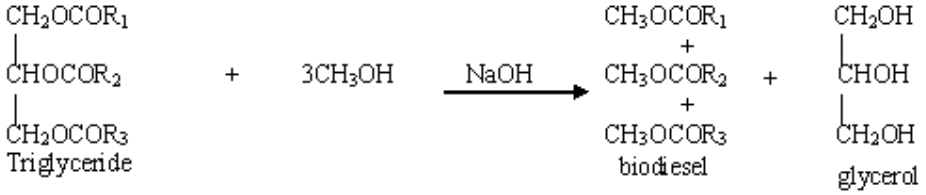
Disadvantages

a) Alcohol lowers the calorific value of petrol
b) Alcohol easily oxidizes to acids. Hence alcohol may cause corrosion.
c) Alcohol absorbs moisture. As a result, separation of alcohol petrol layers takes place. To avoid these blending agents such as benzene or toluene are used.

Biodiesel: It is a mixture of mono alkyl esters of long chain fatty acids which can be produced by transesterification of the vegetable oil. The vegetable oils like soya bean oil, palm oil, sunflower oil etc..,

Preparation: It is a mixture of esters produced by the process of transesterification of vegetable oil with excess of methanol in presence of NaOH as catalyst. The resultant mixture containing glycerol is

removed by gravity separation method; the esters are used as an alternative fuel to diesel in automobiles.



Where R1, R2 and R3 are long chain fatty acids in oil.

Advantages: It has higher cetane number (48-60) compared to diesel (40-55), non toxic and eco friendly products are formed.

Disadvantages: Cost of production is high, Release nitrogen oxide which can lead to the formation of smog and As Biodiesel cleans the dirt from the engine, this dirt can then get collected in the fuel filter, thus clogging it. So, filters have to be changed after the first several hours of biodiesel use.

FUEL CELLS

INTRODUCTION:

Fuel cell is a device, which converts chemical energy of the fuel, and oxidant into electrical energy.Electrical energy is obtained by the combustion of fuels in these galvanic cells. Here, the fuels are supplied from outside and do not form integral part of the cell. These do not store energy. Electrical energy can be obtained continuously as long as the fuels are supplied and the products are removed simultaneously. In these aspects, fuel cells differ from conventional electrochemical cells.

"Fuel cells are galvanic cells which converts chemical energy of the fuels into electrical energy through catalyzed redox reactions with elimination of minimum harmful biproducts".

Fuel is represented as

Fuel / electrode / electrolyte / electrode / oxidant

At anode, fuel undergoes oxidation, When battery discharge potential, the following reactions takes place at respective electrodes.

Fuel $\longrightarrow$ oxidized product + ne

At cathode, oxidant is reduced, oxidant + ne $\longrightarrow$ reduced product

Difference between conventional cell and fuel cell

S. No	Conventional battery	Fuel cells
1	Battery makes electricity from the energy it has stored inside the battery	Fuel cell makes its electricity from fuel in an external fuel tank
2	Battery may run dead	Fuel cell will make electricity as long as fuel is supplied
3	Store chemical energy	Do not store chemical energy
4	Reactants are not supplied and the products are not removed	Reactants are supplied continuously and the products are removed simultaneously
5	Construction cost is high	Construction cost is low
6	Life time is less	Life time is higher than battery
7	Battery produce electricity depends on concentration of the electrolyte	fuel cell will produce electricity as long as it has a fuel supply
8	Recharge of the cell is required.	Recharge of the fuel cell is not required.

Limitation of Fuel cell

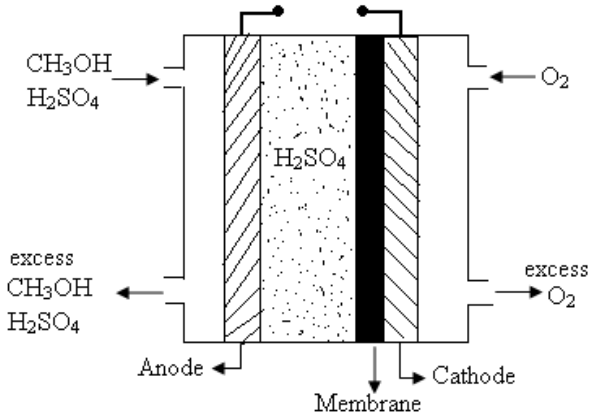
1. Power output is moderate.
2. Fuels are to be stored in tanks under very high pressure in tanks.
3. The refueling and the starting time of fuel cell vehicles are longer and the driving range is shorter than in a "normal" car.
4. It generates only DC and should be converted to AC.

Advantages of fuel cells:

1. Do not pollute the atmosphere
2. Electrical energy can be obtained continuously.
3. Fuel cell provides high quality of DC power.
4. Fuel cells have a higher efficiency than diesel or gas engines.

Methanol – oxygen fuel cell

Fuel: CH_3OH
Oxidant: Oxygen
Electrolyte: H_2SO_4
Voltage: 1.2V



Construction:

1. It consists of anodic and cathodic compartments. Both the compartments contain platinum electrode.
2. Methanol containing H_2SO_4 is passed through anodic compartment. Oxygen is passed through cathodic compartment.
3. Electrolyte used is of sulphuric acid.
4. A membrane made of cellulose is provided which prevents the diffusion of methanol into the cathode.
5. The output voltage is 1.2V.

Working:

Reactions:

At anode: $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e$

At cathode: $3/2O_2 + 6H^+ + 6e \rightarrow 3H_2O$

Net cell reaction $CH_3OH + 3/2O_2 \rightarrow CO_2 + 2H_2O$

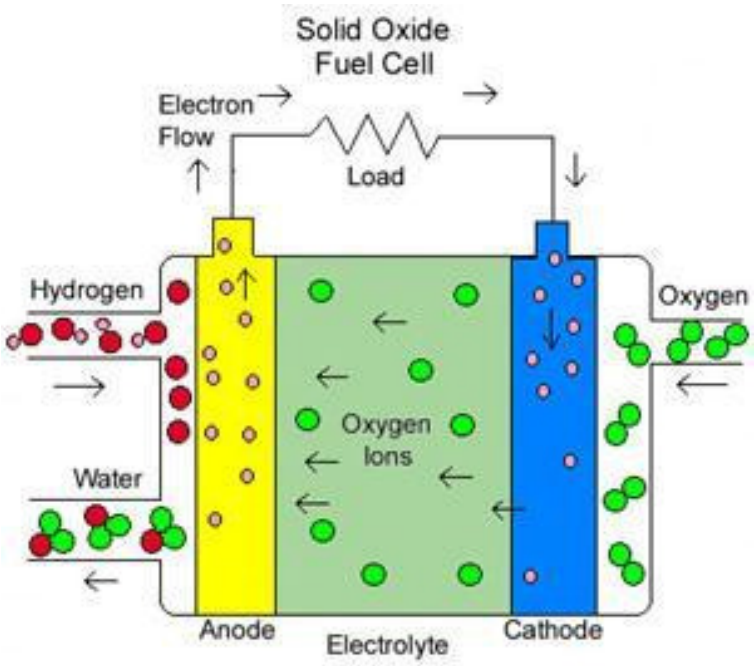
Application:

- Used in military applications
- Large-scale power productions.

Note:

1. *KOH is not used as electrolyte as it reacts with CO_2 and gets converted into carbonate. Thus, conductivity of the electrolyte decreases as well as the efficiency.*
2. *The advantage of acid electrolyte is that the CO_2, a product of the reaction can be easily removed.*

Solid oxide fuel cell (SOFCs): Solid oxide fuel cell is a device which converts gaseous fuel via an electro chemical process directly into electricity.
Fuel: Any gaseous fuel (Natural gas)
Oxidant: Oxygen
Electrolyte: Mixture of yttrium dioxide and zirconium dioxide
Voltage: 1.1V



Construction: It consists of anodic and cathodic compartments. The anodic compartment is made of Nickel oxide or zirconium oxide whereas cathode is made of lanthanum manganate. Electrolyte used is a solid electrolyte like a mixture of yttrium dioxide and zirconium dioxide. Any gaseous fuel (H_2, CO, CH_4 or H_2+CO) is used as a fuel and oxygen is used as oxidant. The cell operates at a temperature of about 1000˚C.

Working:

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

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

Cell reaction: $2H_2 + O_2 \longrightarrow 2H_2O$

Applications:

- It is used for space heating, water heating, etc.,
- It is used as locomotives.

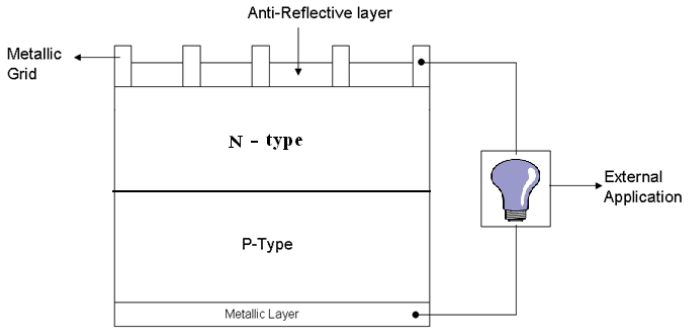
Solar Energy

Photovoltaic cells: (Solar cells) The device which converts solar energy into electrical energy is called photovoltaic cell and the phenomenon is called photovoltaic effect.

Principle: The principle involved is the ejection of electrons from metal surface by striking with photons of solar radiation.

Construction: The device consists of p-n junction diode coated with anti reflective layer (TiO_2). Two electrical contacts is provided, one in the form of metallic grid at the top of the junction and the other is a layer silver on the bottom of the cell. The antireflective layer coated in between the metallic grids allows light to fall on the semiconductor.

Working: The photons of solar radiations enters n-type semiconductor breaks barrier potential and moves to p-type semiconductor where photons knocks the electrons in p type to form electron hole pair. The free electrons so formed will travels through the circuit from n-type and recombines with holes again in p-region. The movement of electrons from n type to p type generates electric current. The electrical energy produced from the solar cell is used for various applications.



Advantages of PV cells: Eco friendly energy conversion devices do not undergo corrode and no moving parts in PV cell, hence no wear and tear

Disadvantages of PV cells: Installation cost is high, produced only during the day time and generates only DC current

Importance of photovoltaic cells: PV cell directly convert sunlight into electricity, do not pollute the nature, to improve remote area communication systems and in transportation systems, milling, sawing etc..,

Production of solar grade silicon (union carbide process)

The production of solar cell grade silicon is carried out in different stages:

In this process SiO_2 is treated with carbon in electric arc furnace at 1500-2000^oC to produce Silicon.

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

The molten silicon obtained is treated with O_2 and fresh silica as flux to remove impurities Al, Ca and Mg.

Metallurgical grade silicon is treated with HCl at 300^oC to form trichlorosilane

$$Si + 3HCl \xrightarrow{300^oC} HSiCl_3 + H_2$$

Trichlorosilane is then passed through fixed bed columns containing ammonium ion exchange resin catalyst where trichlorosilane converts to silicon hydride.

$$6HSiCl_3 \xrightarrow{\text{Ammonium ion exchange resin}} 3H_2SiCl_2 + 3SiCl_4$$

$$3H_2SiCl_2 \xrightarrow{\text{Ammonium ion exchange resin}} SiH_4 + 2HSiCl_3$$

The products are separated by distillation and trichlorosilane are recycled. The poly silicon is obtained through pyrolysis of SiH_4 in silicon seed rods mounted in a metal bell jar reactor..

$$SiH_4 \longrightarrow 2H_2 + Si$$