
Module-3

Fuels and Solar Energy

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 H₂O.

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

O₂. 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 then placed in known weight of H₂O taken in a copper calorimeter and enclosed in air & water jacket to prevent heat exchange with the surrounding. Electrical stirrer is placed on 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.

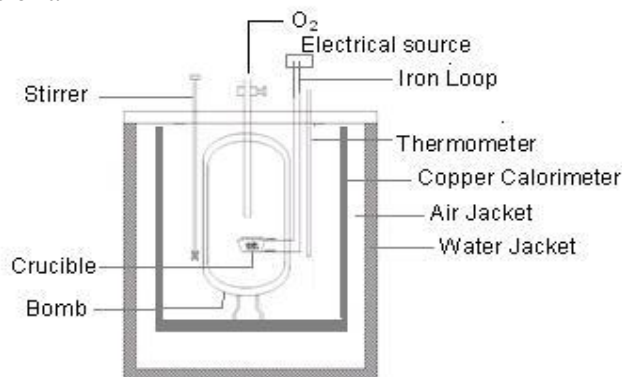
Initial temperature of H₂O is noted. The fuel is

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	= T ₁ °C
Final temperature of water	= T ₂ °C
Change in temperature	= (T ₂ -T ₁) = ΔT °C
Weight of water taken in calorimeter	= ‘W’ kg
Water equivalent of calorimeter	= ‘w’ kg



Specific heat of H₂O

$$= 'S' \text{ J kg}^{-1} \text{ }^{\circ}\text{C}^{-1}$$

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

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

Cracking: “Cracking is a process of splitting long chain or heavy molecular weight hydrocarbon into smaller fragments.



Fluidized bed catalytic cracking

Conditions:

Feed stock: heavy oil

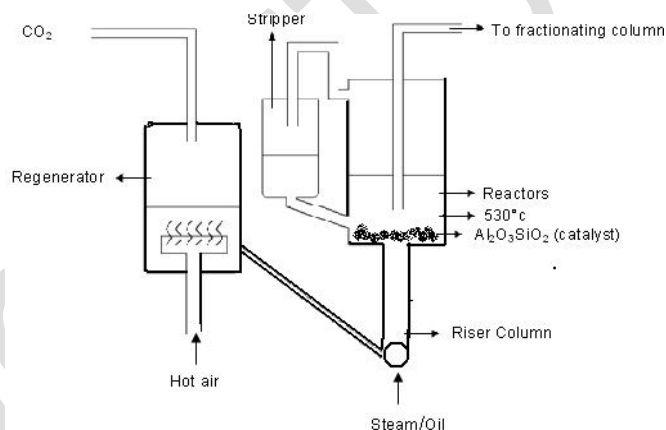
Catalyst: Al₂O₃ + SiO₂ (Alumina silicate)

Cracking Temperature: 530°C

Regenerator temperature: 600°C

Pressure: Little above the normal pressure

In this process, the heavy oil is not fully preheated to 300°C. The oil is sent into reactor through riser column which containing finely powdered catalyst temperature maintained at 700°C. Cracking occurs in a contact time of three seconds and temperature falls to 530°C. The products obtained are subjected to fractionation to separate them to light oil and middle oil fractions.



The catalyst present in the reactor column becomes inactive due to the deposition of carbon over it. The carbon is removed as carbon dioxide by passing hot air into the regenerator chamber at 600°C. The activated catalyst is again fed into reactor for further cracking processes. Due to high contact between oil and catalyst the cracking takes place at higher rate and the yield obtained is 99.99%.

Synthesis of petrol by Fischer-Tropsch process

Synthetic petrol is a mixture of saturated and unsaturated hydrocarbons with composition resembling that of petrol.

Temperature: 200 - 300°C

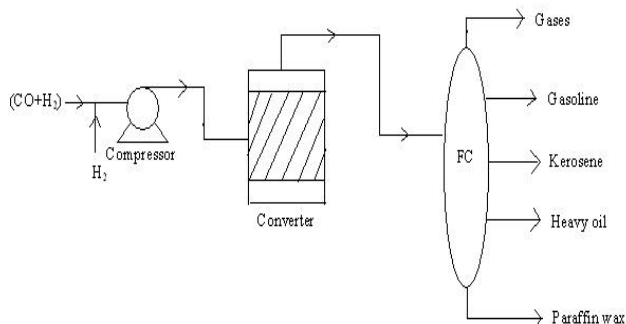
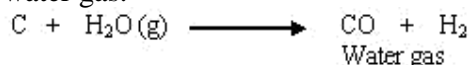
Pressure: 5-25 atm pressure

Catalyst: mixture of cobalt oxide, thorium oxide and magnesium oxide.

Starting material: water gas

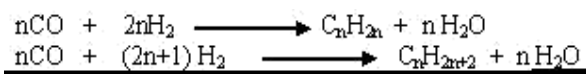
Production of water gas (CO+H₂)

Coke is treated with steam at 1200°C to produce water gas.



The synthesized gas is passed over mixture of Fe₂O₃ and Na₂CO₃ to remove dust, H₂S and organic compounds.

Hydrogenation of water gas: The purified water gas is compressed between 5-25 atm pressures and passed into converter containing mixture of cobalt oxide, thorium oxide and magnesium oxide hydrogenating catalyst the reaction products are saturated and unsaturated hydrocarbons formed between temperature 200-300°C. The nature of the products formed depends on the temperature, pressure and catalyst used.



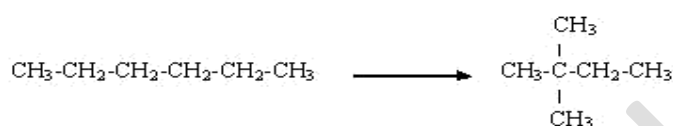
The products are subjected to fractional distillation to obtain petrol.

Reforming: It is the process of modifying structure of hydrocarbon to form new compound without change in the number of carbon in parent chain. The process is carried out by passing petroleum fraction over platinum coated alumina catalyst at 500°C. The main reaction taking place is:

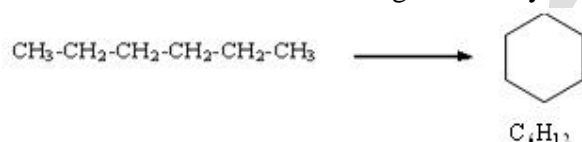
1) Isomerisation:

straight chain hydrocarbon into branched chain.

It is the conversion of straight chain into branched chain.



2) Cyclization: It is the conversion of straight chain hydrocarbon into cycloalkanes.



3) Aromatization: It is the conversion of straight chain hydrocarbon into aromatic.

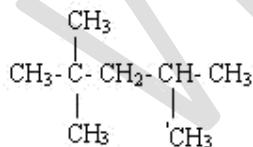


4) Hydro cracking: It is the cracking of a petrol sample in the presence of hydrogen.



Octane numbers: Octane number is the percentage by volume of Isooctane present in the standard mixture of isooctane and n-heptane, which has knocking characteristics as like petrol under test.

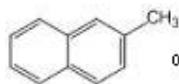
Eg: a petrol sample is said to have octane value 80 when its knocking characteristics matches with 80% of isooctane and 20% of n-heptane.



———— Iso-octane having low knocking tendency, its octane number is 100

$\text{CH}_3\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_3$ — n heptane having high knocking tendency, its octane number is 0

Cetane Number: Cetane number is percentage by volume of n-cetane present in mixture of n-cetane and α-methyl naphthalene which gives the same ignition delay as that of the diesel (fuel) sample under test.



α -Methyl naphthalene (α -Methyl naphthalene having high knocking tendency, cetane no is zero)

$\text{CH}_3-(\text{CH}_2)_{14}-\text{CH}_3$ - n-Cetane (n-Cetane having low knocking tendency, cetane no = 100)

Knocking and its mechanism

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

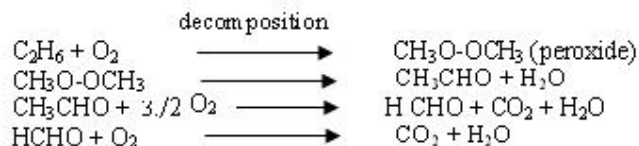
The efficiency of an IC engine depends on the **Compression ratio**.

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

The petrol-air mixture drawn in the cylinder is compressed and ignited. Under ideal conditions (eg, CR-5 to 10) the hydrocarbons undergo combustion and the flame propagates smoothly to produce power.



But, if the hydrocarbon present is unable to withstand pressure at high compression ratio ($\text{CR} > 10$), 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.



Knocking of Diesel engine

In diesel engine first air is drawn into the cylinder and compressed at high pressure. At this stage fuel is injected into the cylinder. Heat produced (above 500°C) from the compressed air ignites the diesel fuel and releases gases which push the piston and cycle is completed by removal of hot gases from the cylinder.

The interval between the start of fuel injection and its ignition is called ignition delay or ignition lag. If the fuel has long ignition lag, then injected fuel accumulates in the cylinder when ignition takes place, it burns violently at high temperature and pressure. This produces a rattling sound, is known as knocking of diesel engine.

III 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

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.

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.

Unleaded Petrol: The gasoline in which the antiknocking properties are increased without addition of lead substance is called unleaded petrol. In order 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 CO_2 and N_2 .

Power alcohol

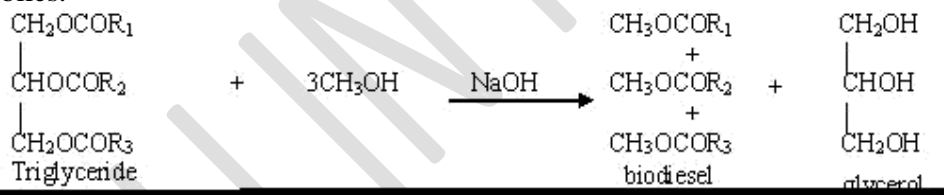
Power alcohol is alcohol petrol blend containing 25% of alcohol and 75% of petrol. It is used as fuel in internal combustion engine.

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.
- 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 R_1 , R_2 and R_3 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.

Solar Energy

Utilization of solar energy

- ☐ To provide electricity to satellites
- ☐ It is used in watches, calculators and other electronic devices as power supply source.
- ☐ It meets the energy requirements for lighting, irrigation and other essential in remote places.
- ☐ It is directly used for cooking, heating water and other various domestic use.

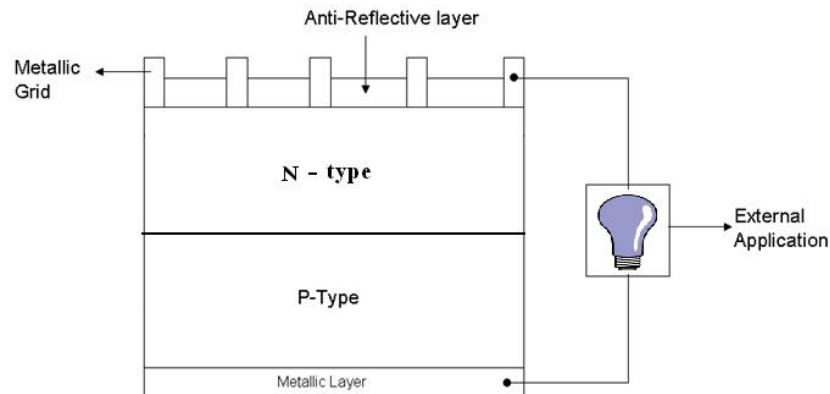
Conversion of solar energy

Solar energy can be converted into more useful forms of energies in two different ways thermal and photo conversion.

Thermal conversion involves the conversion of solar energy into heat energy the energy so produced used for domestic purpose.

Photo conversion involves the conversion of solar energy into electricity by photoelectric effect. In this photons of light strike the electrons on the metal surface. The electrons exist from the metal surface and pass through external circuit producing electrical 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 coated with anti reflective layer (TiO_2). Two electrical contacts are 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 enter the n-type semiconductor, break the barrier potential, and move to the p-type semiconductor where photons knock the electrons in the p-type to form an electron-hole pair. The free electrons so formed will travel through the circuit from n-type and recombine with holes again in the 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 corrosion and have no moving parts in PV cell, hence no wear and tear.

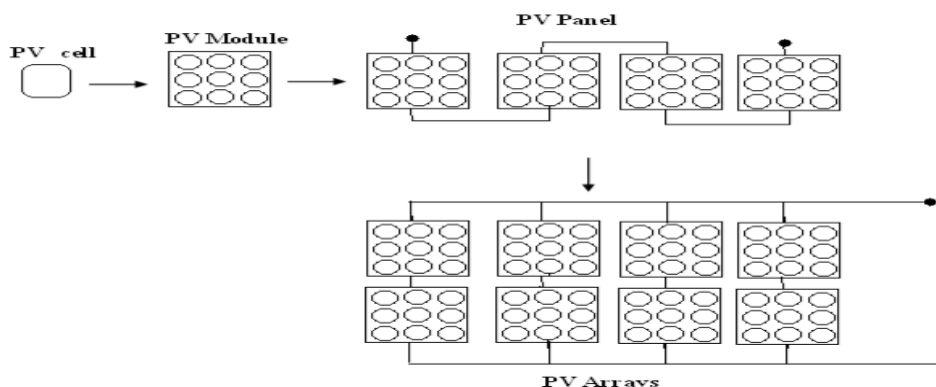
Disadvantages of PV cells: Installation cost is high, produced only during the day time and generates only DC current.

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

P : modules, panels & arrays

Photovoltaic module: A number of solar cells electrically connected to each other and mounted in a support frame are called as **photovoltaic module**. Modules are designed to supply electricity of 12 V, **Photovoltaic panels:** PV panels include two or more PV modules assembled in series; it generates and supply electricity in commercial and residential applications.

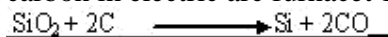
Photovoltaic Arrays: The solar panels are linked together to get an array, the modules are usually first connected in series to obtain the desired voltage, the individual strings are then connected in parallel to allow the system to produce more current.



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 $1500-2000^\circ\text{C}$ to produce Silicon.

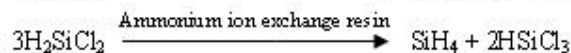
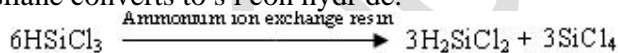


The molten silicon obtained is treated with O_2 and fresh silica as flux to remove impurities Al, Ca and Mg.

Metallurgical grade silicon is treated with HCl at 300°C to form trichlorosilane



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



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

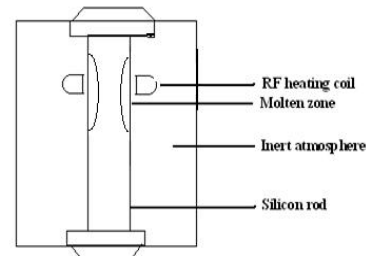


Doping: The doping is a process of adding of impurity/atoms to pure semiconductor material to produce n or p type semiconductor.

Diffusion technique (n&p types): The doping of silicon is effectively done by diffusion method. When silicon wafer is heated just below melting point in an atmosphere of penta valent (P or As) or tri valent impurities (Boron) it becomes soft, the impurity atom condenses on the surface and slowly diffuses into crystal lattice and occupies the position to form either n-type or p-type semiconductor.

Purification of silicon (zone refining)

In this process a silicon rod is clamped vertically and heated by RF coil (Radio frequency) to its melting temperature. Part of solid is heated to melt, the impurities concentrate in molten zone. The molten zone is carefully moved to end of solid material by moving RF coil from top to bottom. When the process is repeated all the impurities concentrate at bottom portion of the rod, finally rod is removed by cutting. The pure silicon is cut into thin wafers and doped suitably to get p-n junction.



At the interface of the solid and the melt, there will be distribution of impurities. The distribution can be represented by distribution coefficient (K_d), Smaller K_d value gives better purification.

$$K_d = \frac{\text{Concentration of impurity in solid phase}}{\text{Concentration of impurity in molten phase}}$$