

Module – 3

Energy Systems

Chemical Fuels:

Defⁿ: - Fuel is a carbonaceous combustible substance which on combustion liberates a large amount of energy in the form of heat.

Classification of fuels: Fuels are classified based on occurrence & State of aggregation or state of phase.

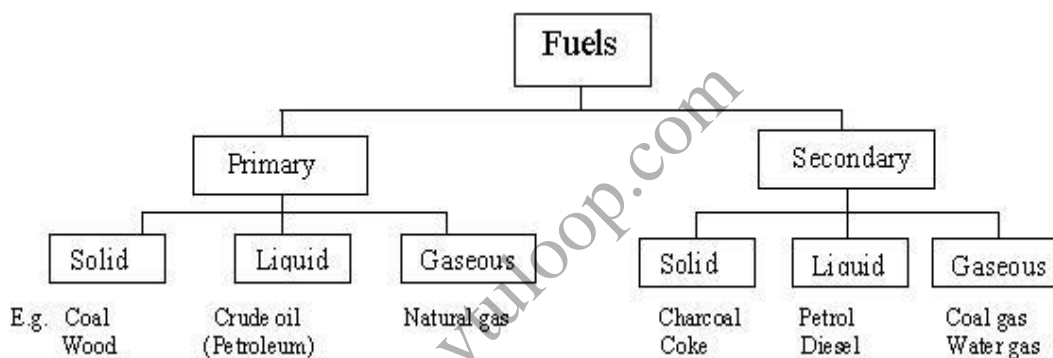
Based on occurrence fuels are classified as.

1) *Primary fuels or Natural fuels*

2) *Secondary fuels or Artificial fuels.*

Secondary fuels are those which are derived from primary fuels.

Eg. Coke, charcoal, diesel, producer gas etc.

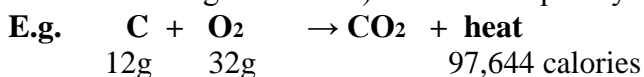


Characteristics of a good fuel:

1. High calorific value
2. Moderate ignition temperature
3. Low ash content
4. Low moisture content
5. No harmful combustion products
6. Combustion control
7. Ease of availability
8. Ease of storage and transport

Calorific value:

It's defined as the "Total quantity of heat liberated when a unit weight of the substance (or unit volume in gaseous fuel) is burnt completely in air or oxygen".



i.e 12g of carbon on burning liberates 97,644 calories of heat energy on complete combustion . Therefore 1g of carbon on complete combustion liberates 8137 calories of heat energy.

Calorific value is expressed in 'Kilojoules/Kg' for solids & liquids types of fuels & 'Kilojoules /m³' for gaseous fuels. It's also expressed as calorie/gm or Kilocalories / Kg.

Types of calorific value:

1. Gross calorific value(GCV) / Higher calorific value(HCV)
2. Net calorific value (NCV) / Lower calorific value (NCV)

Gross calorific value(GCV): *It is the amount of heat liberated when a unit mass or a unit volume of the fuel is burnt completely in air or oxygen and the products of combustion are cooled to ambient temperature(288K).*

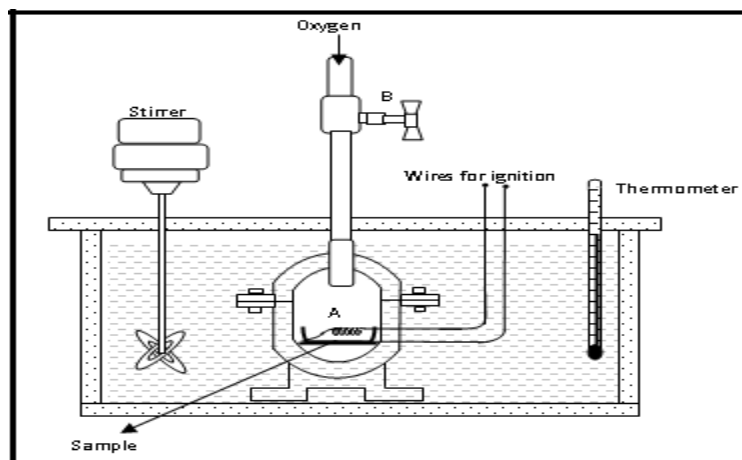
Fuels generally contain some amount of hydrogen during combustion the hydrogen is converted into steam. When the products are cooled to the room temperature the latent heat of condensation of steam gets included in the experimentally measured calorific value, therefore, the experimentally measured calorific value is usually little higher than normal value & hence called HCV.

$$\text{GCV} = \text{NCV} + \text{Latent heat of condensation}$$

Net calorific value (NCV): *'It is defined as the total amount of heat energy liberated when one unit of fuel undergoes complete combustion and the products of combustion are allowed to escape'. Here water vapour, moisture & hot combustible gases are allowed to escape therefore lesser amount of heat energy is available and hence the calorific value will be little less than the normal value hence called lower calorific value.*

$$\text{NCV} = \text{GCV} - \text{Latent heat of condensation}$$

Determination of calorific value of solid & liquid fuel using Bomb Calorimeter:



Principle: A known weight of the sample is burnt completely in excess of oxygen. The liberated heat is absorbed by the surrounding water & calorimeter. Thus the heat liberated during the combustion of fuel is equal to the heat absorbed by water and calorimeter.

Construction:

- The bomb calorimeter (shown in the fig.) consists of an outer cylindrical steel vessel (bomb) with an airtight screw and an inlet for oxygen.
- The bomb has a platinum crucible with a loop of wire. The ends of the wire project out and can be connected to a source of electric current.
- The bomb is immersed in the rectangular vessel (calorimeter) containing water, which is continuously stirred.
- A Beckmann thermometer is introduced into the calorimeter.

Working:

- A known mass of the fuel is made into a pellet and taken in the crucible.
- Oxygen is passed through the bomb.
- A known mass of water is taken in the calorimeter and is closed with the lid.
- The initial temperature of the water is noted.
- The ends of the wire are connected to an electric source so as to ignite the fuel.
- The heat released is absorbed by water. The temperature of water rises.
- The final temperature is noted.

Observation & calculations:

Mass of the fuel = m kg
 Mass of the water = W kg
 Water equivalent of calorimeter = w kg
 Initial temp. of water = t_1 °C
 Final temp. of water = t_2 °C
 Specific heat of water = S KJ/kg/°C

$$\text{GCV} = \frac{(W+w) \times (t_2-t_1) \times S}{m}$$

Let the fuel contain H percentage of hydrogen



2 atoms of hydrogen produce one molecule of water

2g of hydrogen produce --- 18 g of water

x g of hydrogen produce ---- 9 g of water

x % hydrogen $\equiv \frac{9 \times x}{100}$ g of water = 0.09 × x g of water

NCV = GCV - latent heat of steam formed

= GCV - 0.09 × x × latent heat of steam

Latent heat of steam = 2454 kJ kg⁻¹

$$1 \text{ calorie} = 4.187 \text{ kJ kg}^{-1}$$

$$\boxed{\text{NCV} = \text{GCV} - 0.09 \times \text{H} \times 2454}$$

1) When 0.84 g of coal was burnt completely in Bomb calorimeter the increase in temperature of 2655 grams of water was 1.85 °C if the water equivalent calorimeter is 156g Calculate GCV.

Solution:

$$\boxed{\text{GCV} = \frac{(\text{W}+\text{w}) \times (\text{t}_2-\text{t}_1) \times \text{S}}{\text{m}}}$$

$$= \frac{(2655+156) \times 10^{-3} \times 1.85 \times 4.187}{0.84 \times 10^{-3}}$$

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

2) Calculate GCV and NCV of a fuel from the following data. Mass of fuel=0.75 g, W=350 g. t =3.02 °C, Mass of water = 1150, % H₂=2.8.

Solution:

$$\boxed{\text{GCV} = \frac{(\text{W}+\text{w}) \times (\text{t}_2-\text{t}_1) \times \text{S}}{\text{m}}}$$

$$= \frac{(1150+350) \times 10^{-3} \times 3.02 \times 4.184}{0.75 \times 10^{-3}}$$

$$\text{GCV} = 25271.36 \text{ KJ/Kg}$$

$$\text{NCV} = \text{GCV} - 0.09 \times \text{H} \times 587 \times 4.184$$

$$= 25271.36 - 0.09 \times 2.8 \times 587 \times 4.184$$

$$\text{NCV} = 24652.44 \text{ KJ/Kg}$$

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

Mass of fuel =0.83 g, W=3500 g., w = 385 g, t₂=29.2 °C, t₁ = 26.5 °C, % H₂ = 0.7 and S = 4.2 kJ/kg/ °c.

$$\boxed{\text{GCV} = \frac{(\text{W}+\text{w}) \times (\text{t}_2-\text{t}_1) \times \text{S}}{\text{m}}}$$

$$= \frac{(3500 + 0.385) \times (29.2 - 26.5) \times 4.2}{0.83 \times 10^{-3}}$$

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

$$\text{NCV} = \text{GCV} - 0.09 \times \text{H} \times 587 \times 4.184$$

$$= 53079.39 - 0.09 \times 0.7 \times 587 \times 4.2$$

$$\text{NCV} = 52924.07 \text{ KJ/Kg}$$

4) Calculate the gross calorific value and net calorific value of a sample of coal 0.5g when burnt in a bomb calorimeter, raised the temperature of 1000g of water from 293K to 301.6K. The water equivalent of the calorimeter is 350 g. The specific heat of water is 4.187 kJ kg⁻¹K⁻¹, latent heat of steam is 2457.2 kJkg⁻¹. the coal sample contains 93% carbon, 5% hydrogen and 2% ash.

Solution:

m = mass of the fuel	= 0.5 g
W = mass of water taken	= 1000 g
w = water equivalent of calorimeter	= 350 g
t ₁ = initial temperature of water	= 293K
t ₂ = final temperature of water	= 296.4 K
s = specific heat of water	= 4.187 kJ kg ⁻¹ K ⁻¹

$$\begin{aligned}
 \text{GCV (solid fuel)} &= \frac{(W+w) \times (t_2-t_1) \times s}{m} \\
 &= \frac{(1000+350) \text{ g} \times (296.4-293)\text{K} \times 4.187 \text{ kJ kg}^{-1}\text{K}^{-1}}{0.5\text{g}} \\
 &= \frac{1350 \text{ g} \times 3.4 \text{ K} \times 4.187 \text{ kJ kg}^{-1}\text{K}^{-1}}{0.5\text{g}} \\
 &= 97222.14 \text{ kJ kg}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 \text{NCV (solid fuel)} &= \text{GCV} - \text{latent heat} \\
 &= \text{G.C.V} - (0.09 \times \% \text{ of H}) \times \text{latent heat} \\
 &= 97222.14 \text{ kJ kg}^{-1} - (0.09 \times 5) \times 2457.2 \text{ kJ kg}^{-1} \\
 &= 97222.14 \text{ kJ kg}^{-1} - 1106 \text{ kJ kg}^{-1} \\
 &= 94764.94 \text{ kJ kg}^{-1}
 \end{aligned}$$

Octane Number:

Defⁿ: It's the percentage of Isooctane present in a standard mixture of isooctane and n-heptanes which knocks at the same compression as the petrol being tested.

Cetane number:

Defⁿ: It's the percentage by volume of Cetane present in a mixture of cetane or hexadecane and α - Methyl naphthalene which has the same knocking characteristics as the diesel under test.

Knocking:

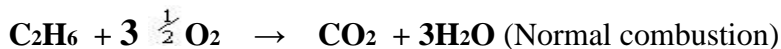
“The production of shock waves in an IC engine as a result of an explosive combustion of fuel-air mixture consequent to an increase in the compression ratio, beyond a certain value leading to a rattling sound”.

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

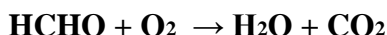
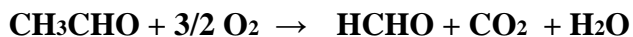
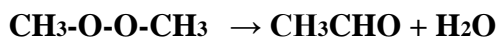
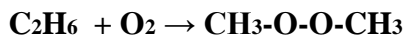
Under ideal conditions, in an IC engine, the petrol-air mixture drawn into the cylinder of the engine undergoes compression and then ignited. The hydrocarbons in the petrol undergo complete combustion and the flame propagates smoothly. But sometimes due to deposits of carbon on the walls of the cylinder the hydrocarbons in the petrol form peroxy compounds. The accumulated peroxides decompose suddenly and burst into flames producing shock waves. This wave hits the walls of the engine and the piston with a rattling sound.

The reactions that take place in an IC engine are given below

Under ideal conditions:



Under Knocking conditions: (Explosive combustion)



The overall reaction is the same under both the conditions. One molecule of ethane reacts with $3 \frac{1}{2}$ molecules of oxygen forming carbon dioxide and water with the release of energy. Under ideal condition, the energy is released at a uniform rate but under knocking conditions, the energy is released slowly at first followed by a lag (formation of peroxide) and finally the energy is released at a very fast rate (decomposition of peroxides).

Effects of knocking:

0. Decreases life of the engine.
1. Causes piston wrap.
2. Consumption of fuel is more.

Prevention of Knocking

1. The use of a fuel with high octane rating, which increases the combustion temperature of the fuel and reduces the proclivity to detonate
2. Enriching the air–fuel ratio which alters the chemical reactions during combustion, reduces the combustion temperature and increases the margin above detonation
3. Reducing peak cylinder pressure.
4. Decreasing the manifold pressure by reducing the throttle opening or boost pressure.
5. Reducing the load on the engine
6. Retarding (reduce) ignition timing

Unleaded Petrol(MTBE):

Methyl tertiary butyl ether (MTBE) is added to petrol (unleaded) to boost its octane number. The oxygen of MTBE brings about complete combustion of petrol preventing peroxide formation and hence knocking is prevented.

- It can be used in IC engine with a catalytic converter.

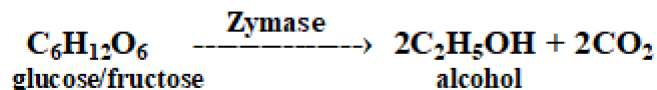
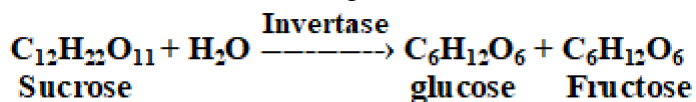
Power Alcohol:

When ethanol (C₂H₅OH) is used as an additive to motor fuels to act as a fuel for IC engines, is called power alcohol. Power alcohol is a gasoline blend containing ethanol.

Gasohol is a blend of 10-85% of absolute ethanol and 90-15% of petrol by volume and is used as a fuel in the United States.

Ethanol is manufactured from saccharine such as molasses – a dark coloured viscous liquid left after the crystallization of cane sugar from cane juice or suger cane.

Molasses - 50-55% total suger of which 35 – 40% is sucrose or cane suger.



Alcohol contains higher percentage of oxygen than MTBE and hence brings about complete oxidation of petrol more effectively. It has better antiknocking characteristics than unleaded petrol.

Advantages

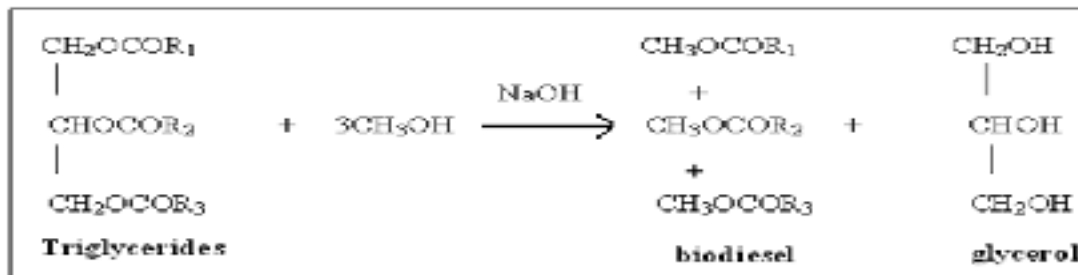
1). Power output is high. 2). Doesn't release CO, causes less pollution. 3). Alcohol is obtained from molasses, an agricultural product and hence renewable. 4). Biodegradable.

Disdvantages

1). Alcohol lowers the calorific value of petrol.
2). Alcohol is easily oxidized to acids, hence alcohol may cause corrosion.
3). Alohoh absorbs moisture and as a result separation of alcohol and petrol layers takes place especially at low temperature.

Biodiesel

It's a clean burning fuel obtained from the renewable resources such as vegetable oils like palm, soya bean, peanut etc. which are all triglycerides. But they cannot be conventionally used in diesel engines because they have high viscosity , high flash point & low volumetric heating value hence they are subjected to trans esterification reaction with excess methanol in presence of catalyst. The product mixture is monomethyl ester of long chain fatty acids & glycerin. The mixture is allowed to settle & the bottom glycerin layer is drawn off. The upper layer of methyl esters is washed & purified further to remove excess amount of methanol. This mixture of methyl esters is called as biodiesel & has the desired characteristics of diesel fuel with cetane no in the range of 50-62 depending on the vegetable oil used for transesterification.



Advantages

1. It is biodegradable, nontoxic hence environment friendly.
2. It can be used as an alternative fuel for compression ignition engine or can be blended with petroleum diesel & used.
3. It is free from sulphur compounds.

FUEL CELLS:

Definition of a fuel cell: Fuel cell can be defined as a galvanic cell in which the electrical energy is directly derived from the combustion of chemical fuels supplied continuously.

Differences between a Conventional cell (battery) and a fuel cell

Battery	Fuel cell
1. It is a device consisting of two or more galvanic cells connected in series or parallel or both. 2. Store chemical energy. 3. Reactants are within the cell. 4. Products remain within the cell. 5. Efficiency is less Ex: Lead-acid battery, Ni-MH battery.	1. It is a galvanic cell in which the electrical energy is directly derived from the combustion of chemical fuels supplied continuously. 2. Do not store chemical energy. 3. Reactants are supplied continuously. 4. Products are continuously removed from the cell. 5. Efficiency is more Ex: H ₂ -O ₂ , Methanol-Oxygen Fuel cell.

Limitations of fuel cells:

1. Fuel cells produce energy only as long as fuels and oxidants are supplied
2. They cannot be recharged because either the raw materials or the products are gases.
3.
 1. Theoretically, the efficiency can be 100%. In practice, the efficiency is 50-80% which is high compared to conventional methods.
 2. Harmful products are absent. Hence fuel cells are environment-friendly.
 3. No need for charging.
 4. Silent operation.
 5. No moving parts. Hence wear and tear are eliminated.

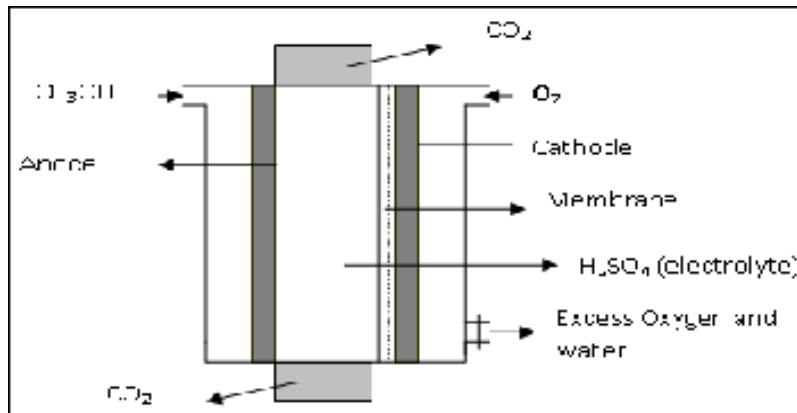
Methanol – Oxygen fuel cell:

Methanol is an efficient electroactive organic fuel at low temperature. The advantages of methanol are (i) It has low carbon content.

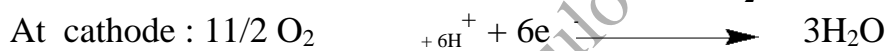
(ii) It has a readily oxidizable OH group.

(iii) It has high solubility in aqueous electrolytes.

Construction: It consists of anode and cathode made of platinum. Sulphuric acid acts as the electrolyte. A membrane is inserted adjacent to the cathode on the electrolyte side to minimize the diffusion of methanol into the cathode. Methanol – H₂SO₄ mixture is circulated through the anode chamber. Pure oxygen is passed through the cathode chamber.



Cell reactions:

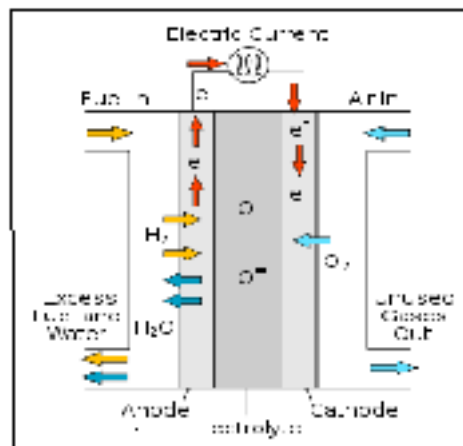


- Uses:** 1) Used in Military applications.
2) Used for large scale power production stations.

Solid oxide fuel cells

A **solid oxide fuel cell** (or **SOFC**) is an electrochemical conversion device that produces electricity directly from oxidizing a fuel. Fuel cells are characterized by their electrolyte material; the SOFC has a solid oxide or ceramic electrolyte. Solid oxide fuel cells are a class of fuel cells characterized by the use of a solid oxide material as the electrolyte. SOFCs use a solid oxide electrolyte to conduct negative oxygen ions from the cathode to the anode. The electrochemical oxidation of the oxygen ions with hydrogen or carbon monoxide thus occurs on the anode side.

Solid oxide fuel cells have a wide variety of applications, from use as auxiliary power units in vehicles to stationary power generation with outputs from 100 W to 2 MW.



SOLAR ENERGY

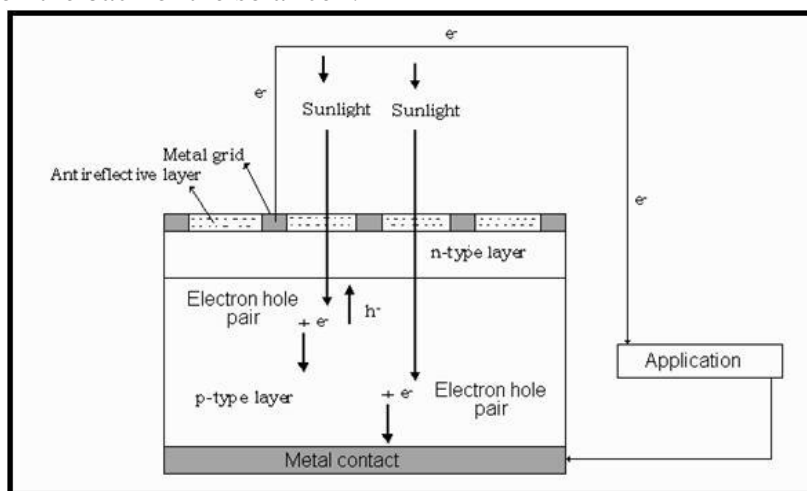
The radiations reaching earth from the sun and converting them into different useful forms of energy is called solar energy. The utilization of solar energy is of two types – Direct solar power and indirect solar power.

Photovoltaic cells

Photovoltaic cells or solar cells are the devices which generate DC current from semiconductors on illumination.

Eg. When semiconductor such as silicon is illuminated by photons (from sunlight) electricity is generated.

Photovoltaic cell consists of a p-n junction formed from a semiconductor diodes of P-type and n- type 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 the other is a layer of nobler metal on the back of the solar cell.



When the light radiation consisting of photon particles incident on the metallic grid of the semiconductor normal to the plane .the photons carry a certain amount of energy

given by $E = hc/\lambda$ Where h is planck's constant c is the velocity of light and λ is the wavelength of the radiation . Those photons which posses the energy greater than E_g are absorbed .The electrons acquire this energy & are removed which leads to the formation of electron hole pair. These electrons are driven out into the external circuit and could be stored and used for various applications such as spinning of fan, working of a motor etc.

Advantages:

1. The Solar power is pollution free.
2. It can operated with little maintenance or intervention after initial setup.
3. The Solar power is becoming more and more economical as costs associated with production decreases, and the technology becomes more effective in energy conversion.
4. The Solar power can be viewed as a local resource because of original climatic variances.

Disadvantages:

1. The Solar power is only practical in certain areas with a favorable climate and latitude. That is, areas near the tropics and which are relatively cloud free.
2. The Solar power is not available at night.
3. The Solar power decreases during cloudy.
4. The Solar power must be converted into some other form of energy to be stored.
5. Solar cell technologies produce DC power which must be converted to the AC power.

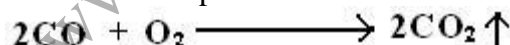
Production of solar grade silicon:

Quartz and carbon are placed in a crucible, two carbon electrodes are submerged in the crucible and an electric arc is struck. The mixture gets heated to a high temperature and the following reaction takes place.



Silicon is obtained in the molten state CO is further oxidized to carbon dioxide & released to atmosphere.

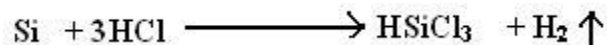
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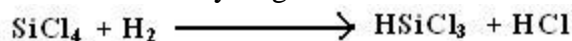
Silicon is further refined by treating with oxygen and slag forming additives such as AL, Ca & Mg. they react with silica to form slag and silicon., the slag is removed and refined melt is poured in moulds where Si solidifies. The silicon obtained is called metallurgical grade silicon.



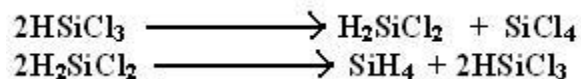
The metallurgical grade silicon is treated with dry HCL gas about 300°C to form trichlorosilane and a small amount of tetrachlorosilane. The mixture is distilled to get pure trichlorosilane.



Silicon tetrachloride is reduced with hydrogen at 1000 °C in a reactor .



The trichloro silanes is then passed through fixed bed columns filled with quaternary ammonium ion exchange resin acting as catalyst.



The products are distilled & separated tetrachlorosilane & trichlorosilane are recycled to the hydrogenation reactor and the exchange resin respectively.

Silicon hydride or silane is further purified by distillation & passed into a reactor containing heated silicon seed rods. Silane gets pyrolyzed to form polysilicon (semiconductor grade silicon).



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