UNIT-III

GEOTHERMAL ENERGY

Energy present as heat (i.e. thermal energy) in the earth's crust. U.S. Geological survey defines geothermal source as all of the heat stored in the earth's crust above 15°C to a depth of 10 km. It occurs when the immense heat energy in the core of earth rises closer to the surface of the earth due to cracks or faults as accounted by the "Plate Techonics Theory", in the crust and heats the surrounded rock.

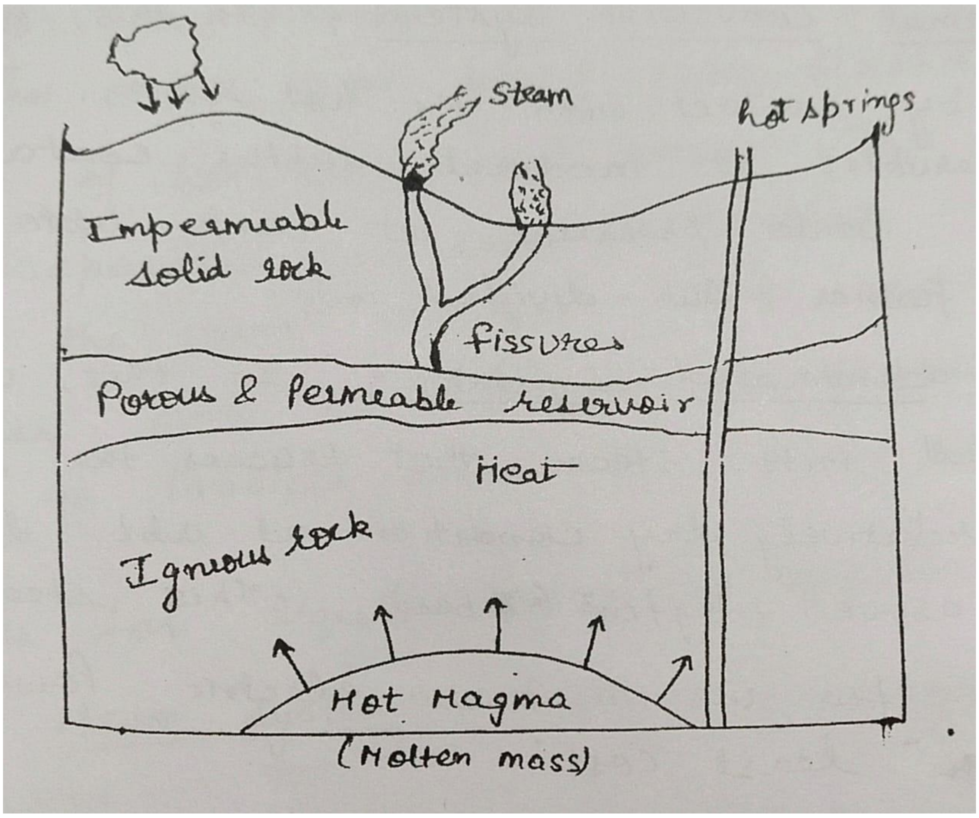

Fig. 1

The hot magma near the surface solidifies into igneous rock. The heat of magma is conducted upward to this igneous rock. Ground water that finds its way down to this rock through will be heated by the heat of the rock. The heated water will the rise convectively upward into porous & permeable reservoir. The reservoir is capped by a layer of impermeable solid rock that traps the hot water in the reservoir. Continuously vented through fissures in the ground, these vents are called fumarols or hot spring.

Geothermal Steam is of two kinds:

Magmetic steam: Originating from magma itself.
Meteoritic steam: Ground water heated by magma.

Geothermal Sources:

1. **Hydrothermal Convective Systems:** In this, water is heated by contact with the =hot rock. These are wet reservoirs at moderate depths containing steam/ hot water under pressure at temperature upto about 350°c.This is further Sub-divided into.

- **Vapour Dominated Systems:** In this water is vaporized into steam that reaches the surface in a relatively dry condition at about 200°c & rarely above 7kg/cm3(~7 bar). This steam is most suitable for use in turbo electric power plants with the least cost.

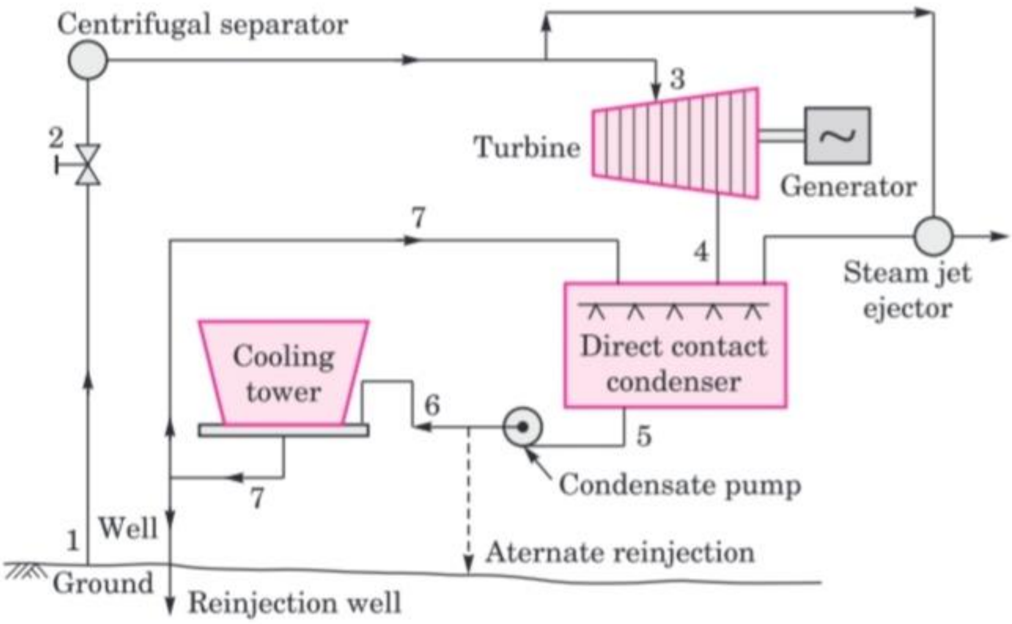

Fig. 2

Dry steam from the wells is collected, filtered to remove abrasive particles and passed through turbine which drive electric generator. The dry steam from the well at perhaps 200°c is used. The turbine flow is not returned to the cycle but reinjected back into the earth.

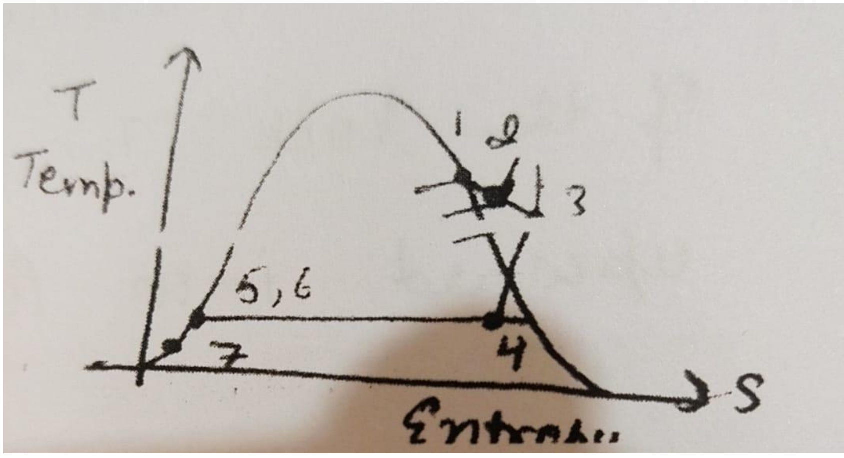

Fig. 3

- **Liquid Dominated Systems:** In this, hot water circulating and trapped underground is at a temp range of 175°c to 300°c. However the water in the reservoir in under pressure. It doesn't boil but remains in the liquid state. When the water comes to the surface the pressure is reduced, rapid boiling the occurs and liquid water flashes into a mixture of hot water and steam. The steam can be separated and used to generate electric power in the usual manner. The remaining hot water can be utilized to generate electric power or to provide space & process heat.

3 methods for liquid dominated system are:

➢ **Flashed steam system:** suitable for water in higher temperature range.

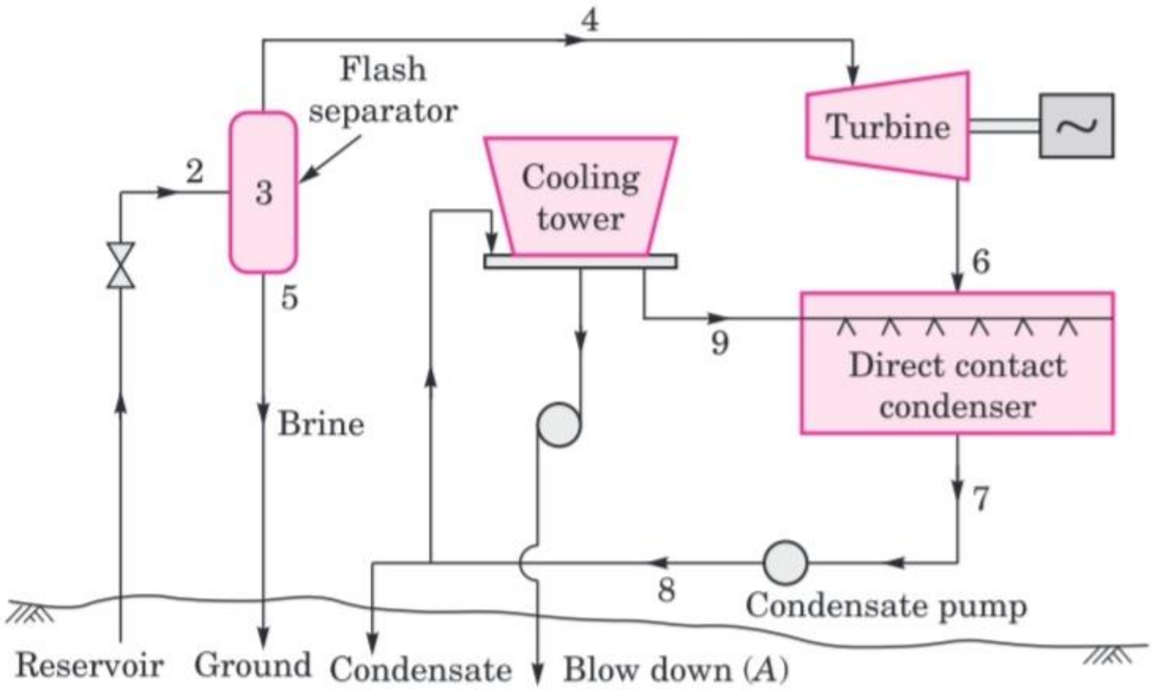

Fig. 4

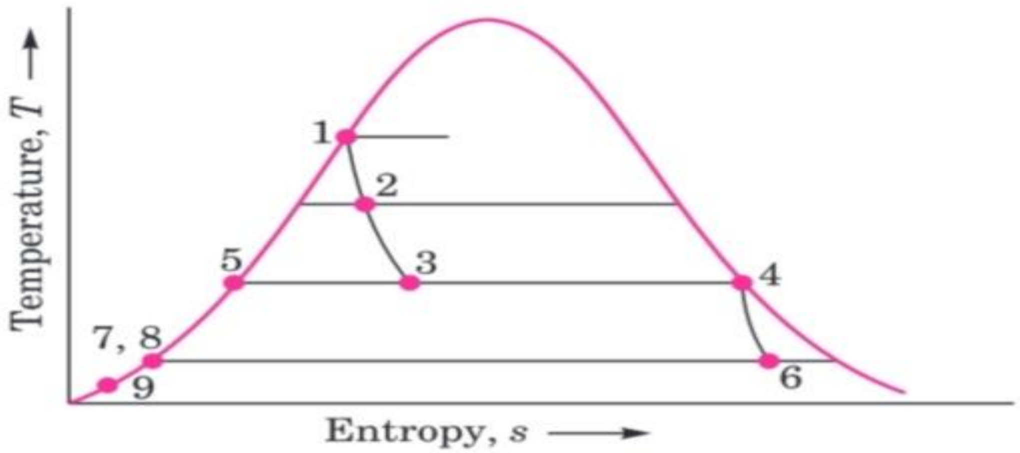

Fig.5

Water from the underground reservoir reaches the well head at lower pressure flash separator results in throttling process of 2-phase mixture. The mixture is separated into dry saturates steam to turbine and saturated brine to the ground. The balance of the condensate after cooling water is recirculated to the condenser is reinjected into the ground.

The power generation from such systems can be made more economical by associating chemical industry with power plant to make use of brine & gaseous effluent.

Limitations:
1 Greater corrosion of piping, well casing& other conduits.
2 Many times temp & Pressure of water may not be sufficient to produce flash steam.

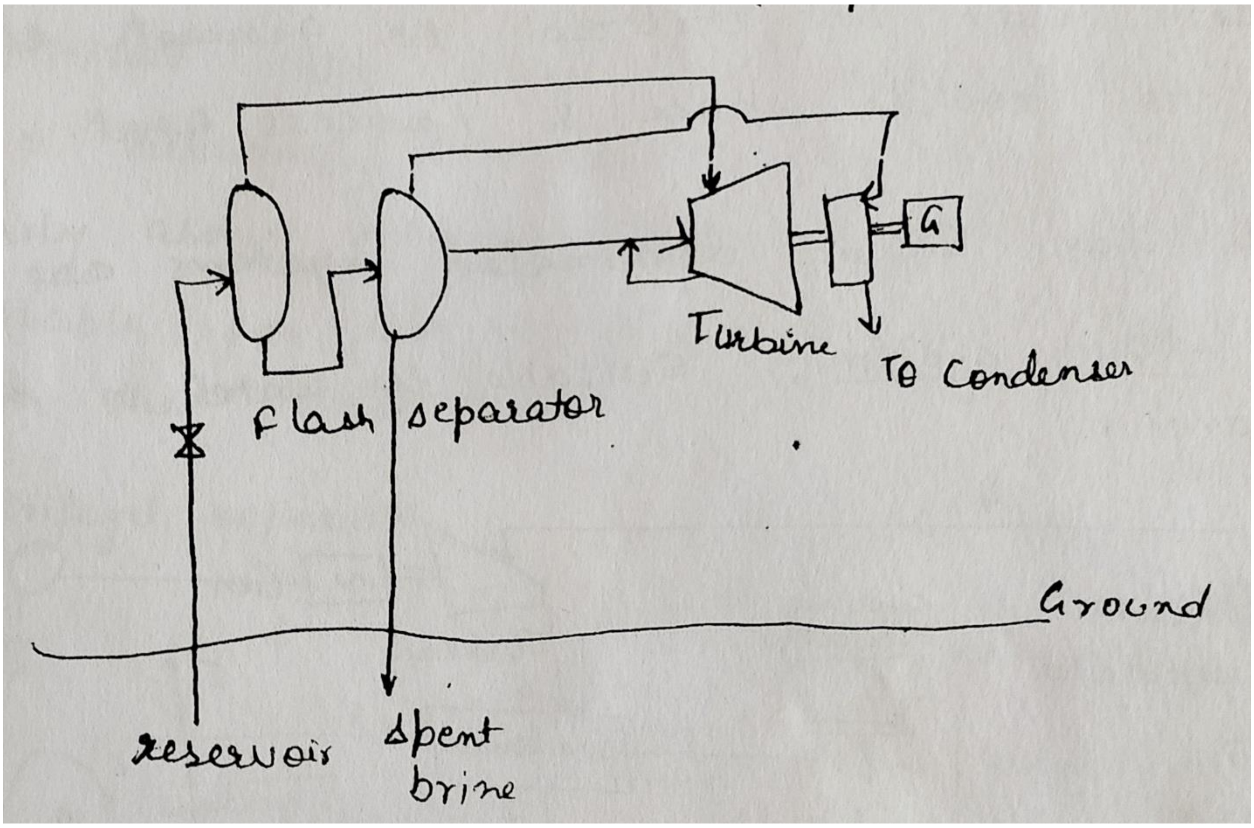

Fig. 6 Double flash Steam system gives more power

- **Binary cycle system:** it is suitable for water at moderate temperature about 50% of hydrothermal water is in the moderate temperature ranges 153 to 205°c. In binary system an organic fluid/Binary fluid (2 fluid) with low boiling point such as is about one C_4H_{10} and freon-12 are usually recommended.

  In order to isolate the turbine from corrosive materials and to accomodate higher concentration of non condensable gases, the binary cycle concept is new receiving considerable attention as an alternate power cycle concept. This is basically a Rankine cycle with an organic working fluid.

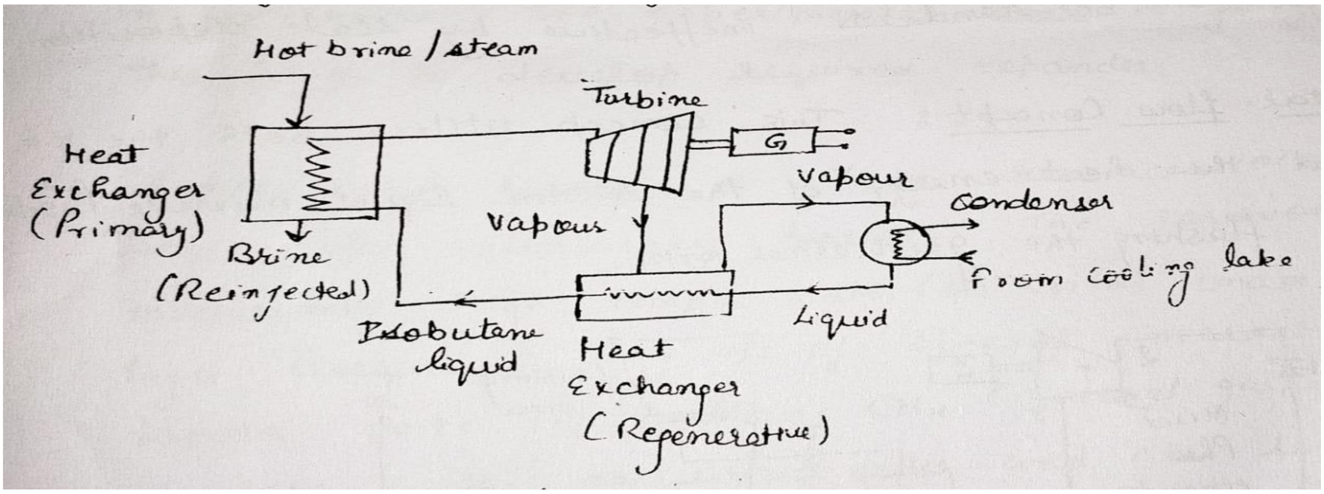

Fig. 7

Hot water or brine from underground reservoir either as unflashed liquid or as steam producing by flashing is circulated through primary heat exchanger. In the heat exchanger the hot brine transfer its heat to the organic fluid thus converting it to a superheated vapour i.e. used in a standard closed Rankine cycle. The vapour drives the turbine generator. The exhaust vapour from the turbine is closed in the regenerative heat exchanger and then condensed, using either air cooler or water cooled condenser and cooling tower. The condensed liquid is returned to the primary heat exchanger by way of regenerative exchanger. The heat exchanger is shell & tube type so that no contact between brine & working fluid takes place. If the temperature & salinity of geothermal brine are not high, the tendency for solides to deposit on surfaces in the heat exchanger is not too great. If it is high, this procedure may not be practical but heat exchangers may soon be rendered ineffective by scale deposition.

- **Total flow concept:**

This concept utilizes both the kinetic energy and the heat energy of the steam liquid mixture produced by flashing the geothermal brine.

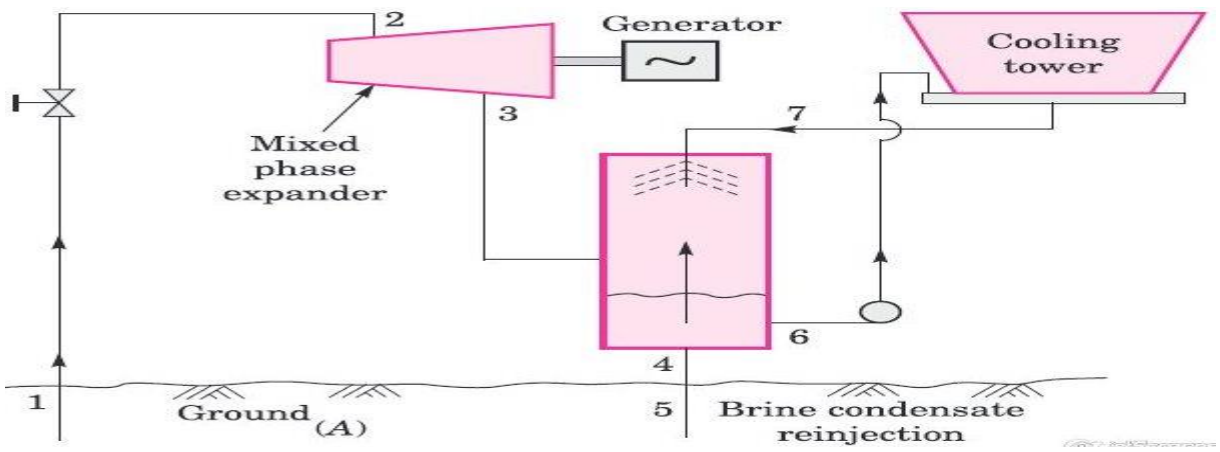

Fig.8 Schematic a liquid dominated total flow concept

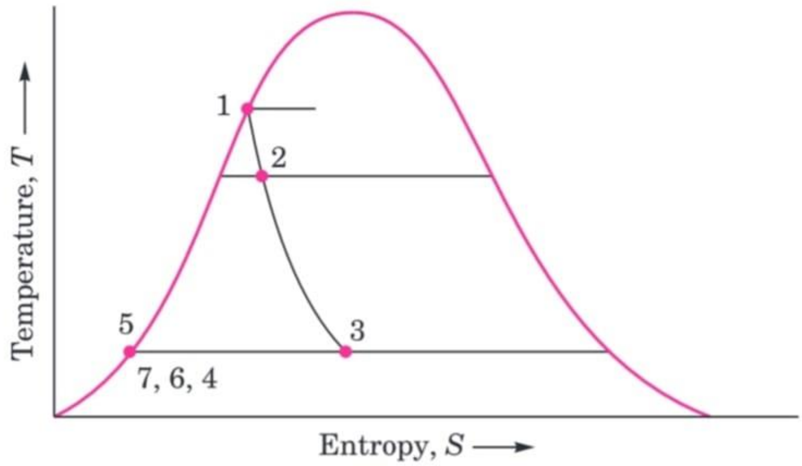

Fig.9 T-S diagram for liquid dominated total flow system

The hot brine from geothermal well is throttled to where it because 2-phase mixture of low quality. The 2 phase at this point are not separated, the full flow is expanded to 3, condensed to 4. Then the brine is reinjected into the ground at 5.

Mixed phase expanders are used to overcome the losses associated with impingement of liquid droplets on blades. They must also be able to withstand the corrosive and erosive effects of the significant quantities of dissolved solids in the brine. The experimental and analytical work is going in this field to develop the required expander.

Geopressured Resources: These resources occur in large, deep sedimentary basins. The reservoirs contain moderately high Temperature water (Or brine) under very high pressure. They are of special interest because substantial amounts of methane CH_4 (natural gas) are dissolved in the pressurized water and are released when pressure is reduced. Geopressured water is tapped in much deeper underground acquifers at depths between 2400 to 9000 m. This water is at relatively low temperature of about 160°c and under very high pressure about 1050 kg/cm^2 (>1000 bar). It has high salinity of 4 to 10% and often referred to as brine.

Hot dry rocks (or petrothermal system) : These systems are composed of hot dry rock (HDR) but no underground water. The rock, occurring at moderate depths, has very low permeability and needs to be fractured to increase its heat transfer surface. The thermal energy of the HDR is extracted by pumping water through a well that has been drilled to the lower part of the fractured rock. The water moves through the fractures, picking up heat. It is then travels up a second well that has been drilled to the upper part of the rock and finally back to the surface. There, it used in a power plant to produce electricity.
There are two methods to tap this geothermal energy. One possible method is to donate a high explosive at the bottom of a well drilled into the rock (nuclear explosion). Another method is to use hydraulic fracturing to produce the heat transfer and permeability required to extract energy at a high rate from hot dry rock.

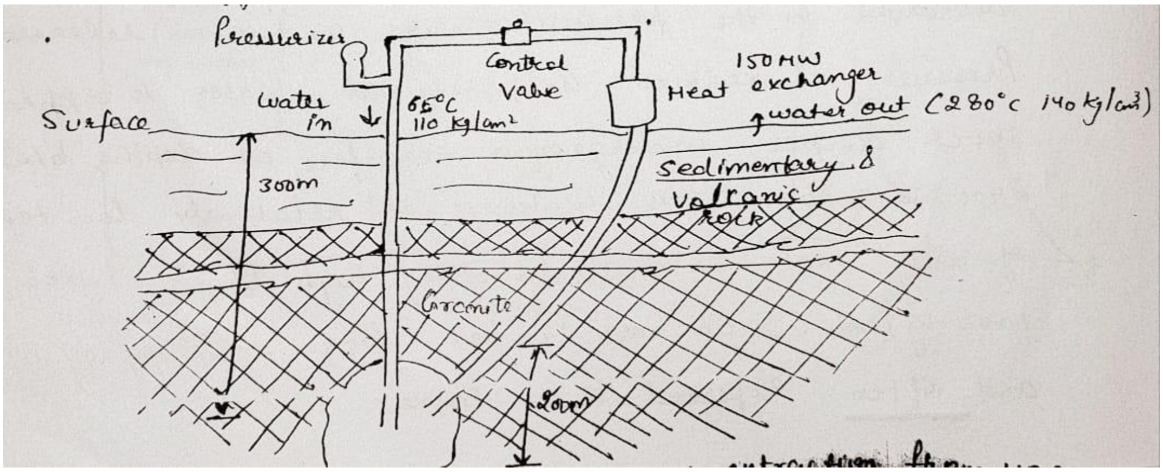

Fig. 10

Magma Resources (Molten Rock chamber systems) : These consists of partially/ completey molten rocks with temperature in excess of 650°c which may be encountered at moderate depths, especially in recently active volcanic regions. These resources have a large geothermal energy content, but very high temperature will make extraction of energy a difficult technological problem.

Advantages of Geothermal energy:

1. Versatile
2. Cheaper compared to energies obtained from fossil fuels.
3. Least polluting
4. Renewable resource
5. Amenability for multiple uses from a single source.

Disadvantages:

1. Overall efficiency is low.
2. Drilling operation is noisy.
3. Large areas are needed.

Application:

1. Generation of electric power.
2. Industrial process heat.
3. Space heating.

Environmental Problems:

1. **Solid particles and non Condensable gases:** steam and water contains dissolved solids and non- Condensable gases. The entrained solids are removed by centrifugal separators at well head. They are further removed by strainers before turbine entry. The non-condensable gases (mostly CO_2+CH_4, H_2, N_2, NH_2, H_2S)

partly escape the atmosphere via particle centrifugal separator, condensor ejector and in some cases cooling towers.

2. **Land erosion:** closer control, replanting of shrubs and trees, more careful site selection and improved construction methods are helping to solve this problem.

3. **Noise:** Exhausts, blow downs and centrifugal separation are some of the sources of noise that necessitate the installation of silencess on some equipment.

4. **Water borne Poisons:** Water phase in wet fields sometimes contain toxic mercury, arsenic, ammonia etc. Which if discharged could contaminate water downstream.

5. **Air borne poisons:** From various points harmful substances may escape into the air at thermal sites. These may contain radioactive materials also. Horizontal well discharge in a controlled direction could be a solution to this problem.

6. **Seismicity:** some fears have been expressed that prolonged geothermal exploitation could trigger off earthquake especially if reinjection is practised in zones.

7. **Heat Pollution:** emission of huge quantities of waste in river water can damage fisheries and encourage growth of unwanted water weeds.

Magneto Hydro Dynamic power Generation (MHD)

As its name implies, magneto hydrodynamics is concerned with the flow of conducting fluid in the presence of magnetic and electric field. An MHD generator is a device for converting heat energy of a fuel directly into electrical energy without a conventional electric generator. In this system, MHD converter system is a heat engine, in which heat taken up at a higher temperature is partly converted into useful (electrical) work and remainder is rejected at a lower temperature.

Principles of MHD Power Generation:
The principal is simple that discovered by Farady:
When an electric conductor moves across a magnetic field, a voltage is induced in it which produces an electric current. This is the principal of conventional generator also, where the conductors consists of copper strips. In MHD generator, solid conductor is replaced by gaseous conductors, an ionized gas. If such a gas is passed through a powerful magnetic field at high velocity, a current is generated and can extracted by placing electrode in a suitable position in a stream. This arrangement provides DC power electricity.

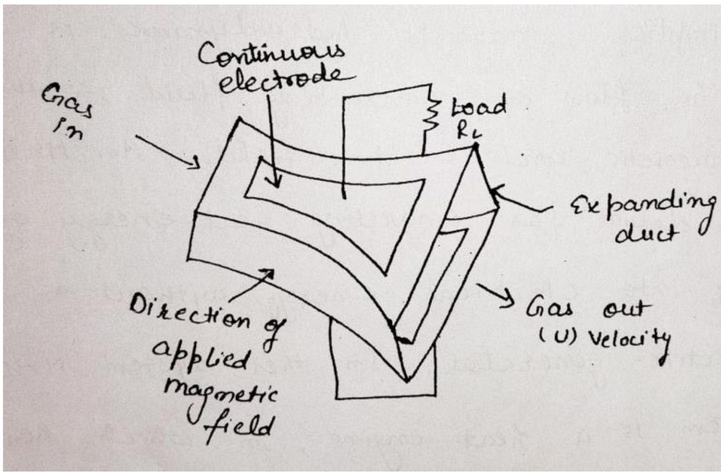

Fig.11

This principle can be explained as follows: An electric conductor moving through a magnetic field experiences a retarding face as well as an induced electric field and current. This effect is a result of Faradays law of EMI. The induced emf is given by:

$E_{ind} = \vec{U} \times \vec{B}$

where, U = velocity of conductor

B = magnetic field intensity

The induced current density in $\vec{J}_{ind} = \sigma \vec{E}_{ind}$

σ = electric conductivity

The Retarding force on the conductor in the Lorentz force

$$\vec{F}_{ind} = \vec{J}_{ind} \times \vec{B}$$

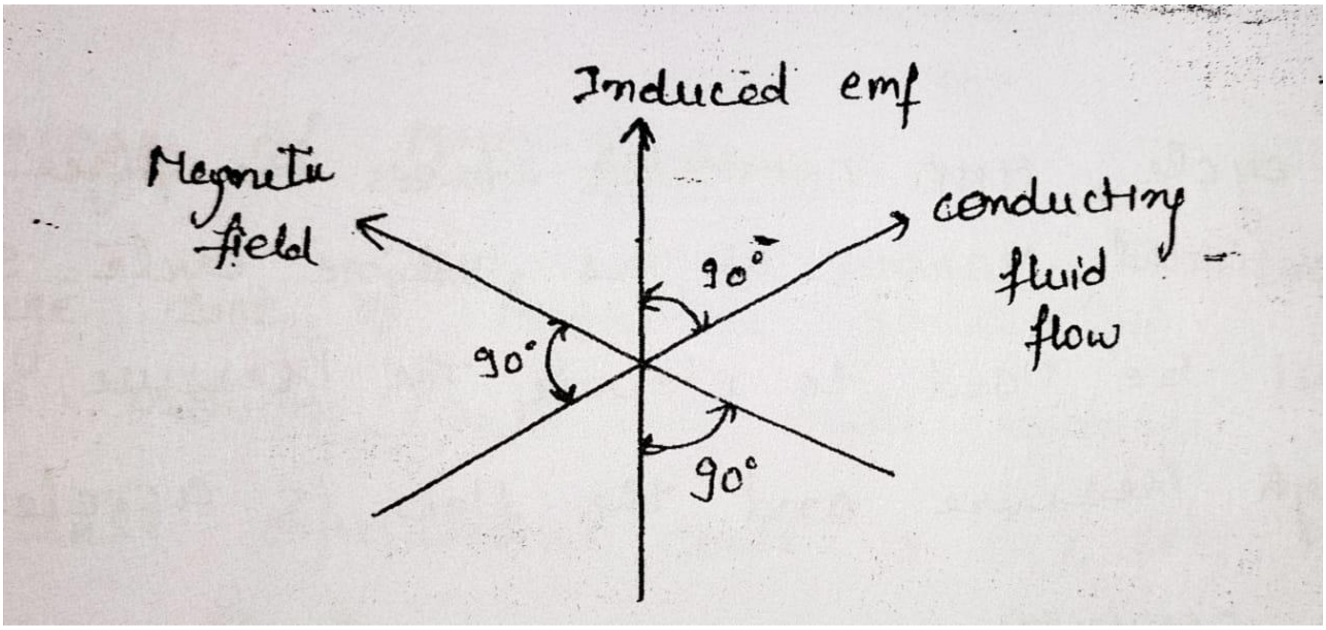

Fig. 12

In MHD generator, conducting flow fluid is forced between the plates with a Kinetic energy and pressure differential sufficient to overcome the magnetic induction force find. An ionized gas is employed as a conducting field. Ionization is induced either by thermal means. i.e. by an elevated temperature or by seeding with substance like cesiumor Potassium vapours which ionize at relatively low temperature.

The other way is to incorporate a liquid metal into a flowing carrier gas since the metal is a good electrical conductor, gas metal mixture can be used as the working fluid in MHD Generator.

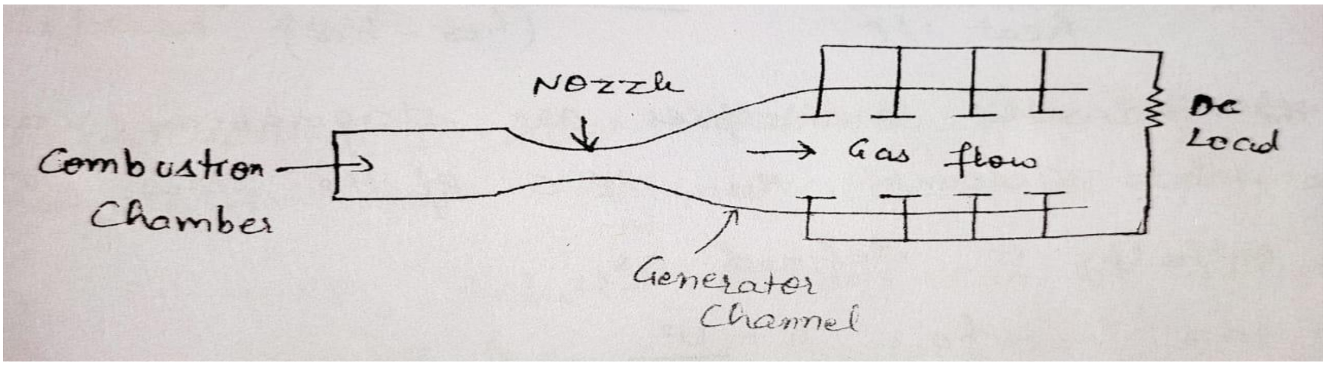

Fig. 13

In overall power cycle, MHD converter takes the place of a turbine in a conventional vapour or gas turbine cycle still, a compressor must be used to elevate the pressure, heat is added at high pressure and the flow is accelerated before entering the converter.

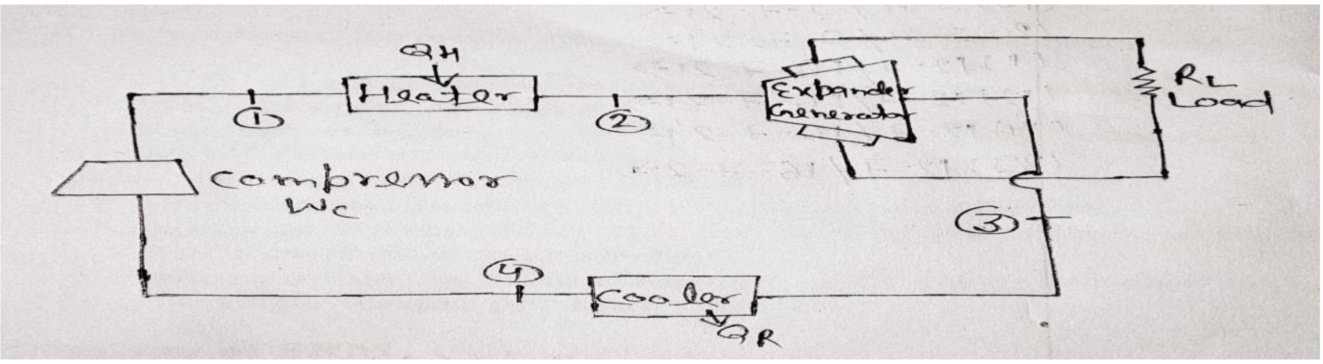

Fig. 14

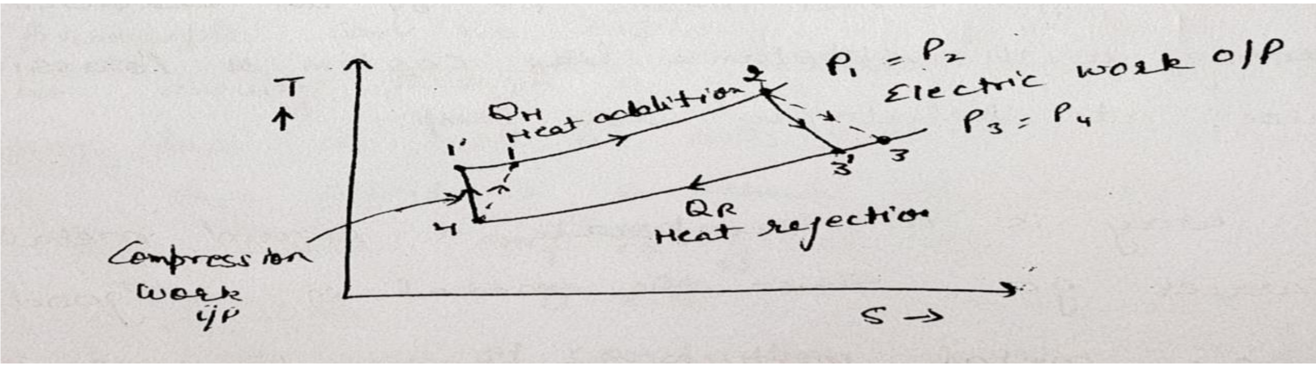

Fig. 15

Thermal Efficiency:

$$\eta_{th} = \frac{\text{work output}}{\text{Heat input}}$$

$$= \frac{(h_{20} - h_{30}) - (h_{10} - h_{40})}{(h_{20} - h_{10})}$$

Where the indicated enthalpies are stagnation values which take into account the K.E. of the flow. The stagnation enthalpy is defined as,

$$h_0 = h + \frac{U^2}{2g_c}$$

U= Flow velocity

Advantage of MHD systems:

1. Large amount of power is generated.
2. No moving parts so more reliable.
3. Overall operational costs is 20% less than conventional steam plants.
4. Direct conversation of heat into electricity permits to eliminate gas turbine (gas turbine power plant) or both boiler & turbine (steam power plant) this reduces losses of energy.
5. Reduced fuel consumption offer conservation of energy resources.

Limitations:

1. The Combuster, MHD generator channel, electrodes and air Preheater are exposed to corrosive combustion gases at very high temperature so life of equipment has been short.
2. Ash residue from burning coal is carried over with combustion gases and tends to cause erosion of exposed surfaces.
3. Separation of seed material from fly ash, & its reconversion into original (carbonate) form.

Slag & seed related problems can be solved by using fuel gas derived from coal rather then coal itself. Advanced concept of hydrogen gas made from coal & water can also be used.

FUEL CELLS

A cell (Combination of cells) capable of generating an electric current by converting the chemical energy of a fuel directly into electrical energy. The fuel cell is similar to other electric cells in the respect that it consists of positive or negative electrodes with an electrolyte between them.
Fuel in the suitable form is supplied to the negative electrode and oxygen often from air to the positive electrode. When cell operates, fuel is oxidised and the chemical reaction provides the energy that is converted into electricity.
Fuel cell different from electric cell in the respect that the active (fuel & O_2) material are not contained within the cell but are supplied from outside. Main uses of fuel cell are in power production, automobile vehicles and in special military use.

Types of fuel cell:
The 1st practical fuel cell was demonstrated by Francis T. Bacin and J. C. frost of Cambridge University in 1959. As per the fuel used, main types of fuel cells are:

1. **Hydrogen (H2) fuel cell:** The main components of fuel cell are:
- Fuel electrode (canode)
- Oxidant/air electrode (cathode)
- Electrolyte

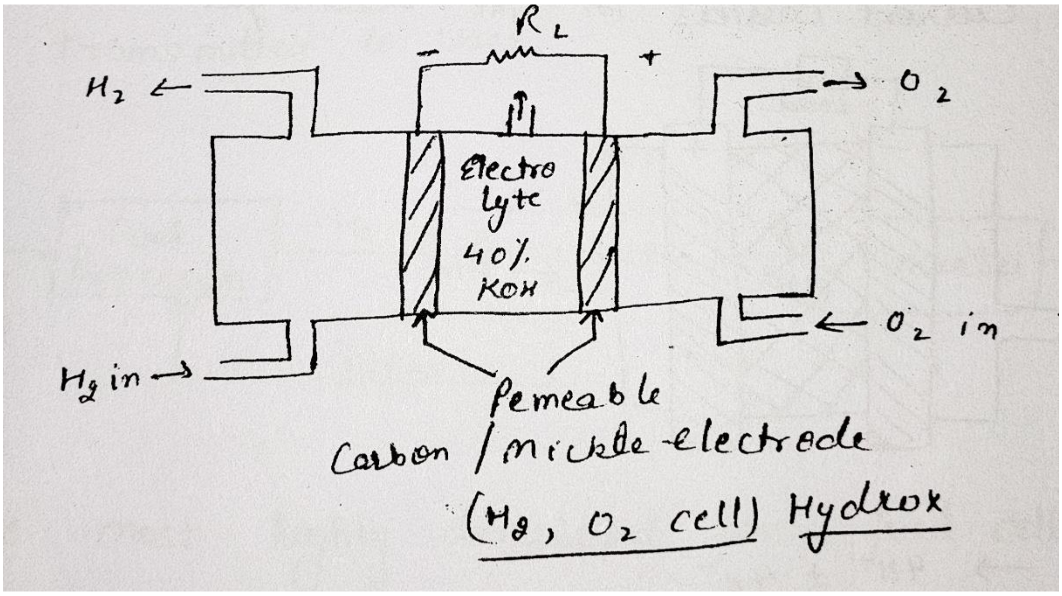

Fig.16

In most fuel cells, H_2 is active material at negative electrode &O_2 at positive electrode because H_2 & O_2 are gases, a fuel cell requires a solid electrical conductor to serve as a current collector and to provide a terminal at reach electrode. The solid electrode material is generally porous.

At negative electrode, H_2 gas is connected into hydrogen ions (H^+)

$$H_2 \longrightarrow 2H^+ + 2e^-$$

$$\frac{1}{2}O_2 + H_2O + 2e^- \longrightarrow 2OH^-$$

Hydrogen & hydroxyl ion combine in electrolyte to Produce water

$$H^+ + OH^- \longrightarrow H_2O$$

$$H_2 + \frac{1}{2}O_2 \longrightarrow H_2O$$

2. **Ion-exchange membrane cell:** It consists of solid electrolyte ion-exchange membrane, electro catalysts and gas feed tubes. The membrane is non- Permeable to the reactant gases,H_2 & O_2, which thus prevents to H^+ ions which are current carries in the electrolyte.

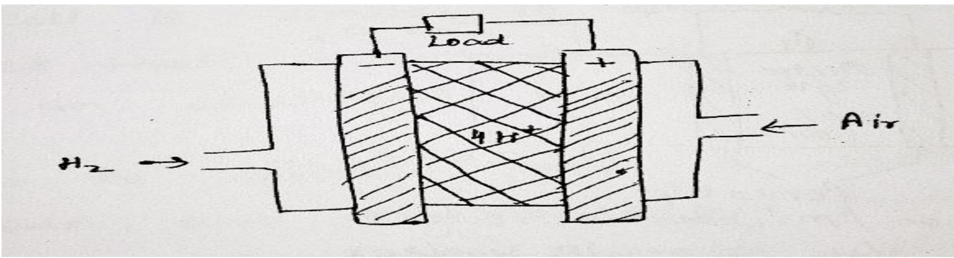

Fig.17

Anode, $2H_2 \longrightarrow 4H^+ + 4e^-$

cathode, $O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$

overall Reaction, $2H_2 + O_2 \longrightarrow 2H_2O$

The desired properties of ion-exchange membrane:

- High ionic conductivity
- Zero electronic conductivity
- Low permeability of fuel &oxidant
- Low degree of electro-osmosis
- High resistance to dehydration
- Mechanical stability

This cell operates at about 40-60°C

Fossil fuel cells:

It has 3 main components:

- Fuel processor which converts fossil fuel into hydrogen rich gas.
- Power section consisting of actual fuel cell
- Inverter for changing DC by fuel cell into ac to be transmitted to user.

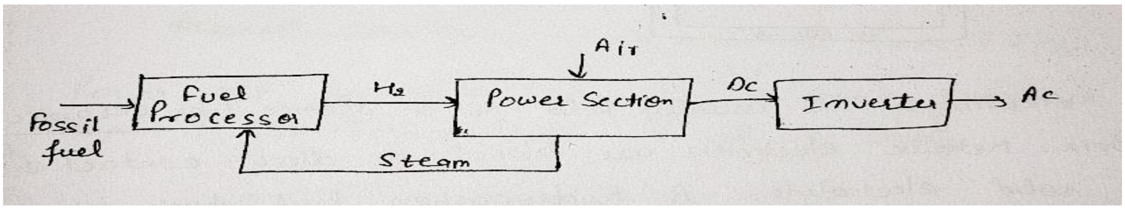

Fig.18

The most highly developed fossil fuel cells are phosphoric acid cells, molten carbonate cells, solid oxide electrolyte cell.

Molten carbonate cell: These are high temperature (600-700°C) fuel cells with a molten carbonate mixture as electrolyte. A special feature of these cells is that during operation they can oxidize CO to CO_2 as well as of H_2 &H_2O. Hence gaseous mixture of H_2 and CO, which are relatively in expensive to manufacture, can be used in the cell, the presence of CO_2 would have only a minor effect.

The mixture of H_2 & CO is supplied to negative electrode & O_2 to positive electrode the discharge emf of the cell is about 0.8V.

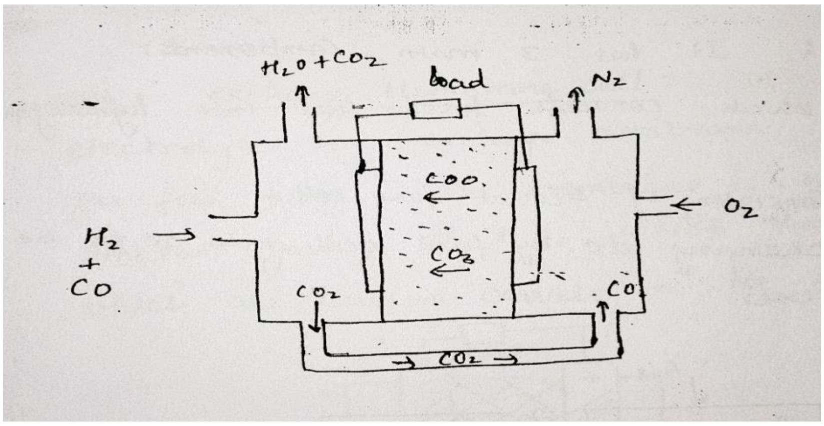

Fig.19

The electrolyte is usually held in a sponge like ceramic matrix. Metallic electrode are placed in direct contact with this solid electrolyte. A hydrocarbon fuel such as methane or kerosene is used. Fuel is reacted inside the cell to produce H_2 & CO.

At fuel electrode: $H_2 + CO_3^{-2} \rightarrow H_2O + CO_2 + 2e^-$

$CO + CO_3^{-2} \rightarrow 2CO_2 + 2e^-$

At O_2 electrode: $O_2 + 2CO_2 + 4e^- \rightarrow 2CO_3^{-2}$

overall Reaction: $H_2 + CO + O_2 \rightarrow H_2O + CO_2$

Solid oxide electrolyte cell: A possible electrolyte in this is zirconium dioxide containing a small amount of another oxide to stabilize the crystal structure other energy sources or fuels are methanol, Ammonia and hydrazine.

A compact fuel cell for mobile source, possibly for vehicle propulsion, utilizes liquid hydrazine (N_2H_4) & Hydrogen peroxide (H_2O_2) or air as the energy source. Hydrazine is injected as required into aqueous potassium hydroxide electrolyte to provide the active material at negative electrode.

$$NH_2NH_2 + 4OH^- \longrightarrow N_2 + 4H_2O + 4e^-$$

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$$

overall Reaction: $NH_2NH_2 + O_2 \longrightarrow N_2 + 2H_2O$

Power output for this is more & main drawback is that it is highly toxic as well as costly.

Advantage of fuel cells:

- Higher efficiency
- Less maintenance required
- Atmospheric pollution is small if primary energy source is H_2
- No noise pollution
- Space requirement is less.

Disadvantages:

- High initial cost.
- Low service life.