PART-B ESSAY QUESTIONS VITH SOLUTIONS

5.1 NEED FOR DEC, CARNOT CYCLE, LIMITATIONS AND PRINCIPES OF DEC, THERMOELECTRIC GENERATORS, SEEBECK, PELTIER, JOULE AND THOMSON EFFECTS, FIGUE OF MERIT, MATERIALS, APPLICATIONS

Q14. Explain the principle of direct energy conversion with exaiples.

Answer : [May-19, (R15), Q11(a) | Model Paper, Q10(a)]

Principle of DEC

According to the principle of direct energy conversion, the transformtion of one type of energy (all naturally available energies such as solar energy, wind energy, etc.) to another form of energy sucas electricity occurs without an intermediate stage (i.e., conversion of energy into mechanical energy).

The use of direct energy conversion devices has been limited to smalscale and special purpose applications, since the voltage output of these devices is small.

Examples

1. **Fuel Cell**

   It is a direct electric conversion device, which converts the chemical energ of a conventional fuel directly into electric enegy.

2. **Solar cell**

   Solar cells convert the sunlight into electricity by using the principle ophotovoltaic effect.

3. **Thermoelectric Generators**

   These devices convert the heat energy directly into the electricity.

Q15. Discuss the need and principle for DEC.

Answer : May-17, (EEE), (R13), Q10(b)

Need for DEC

1. There is no intermediate conversion of energy such as mechanical enery and then to the electricity.
2. Energy losses are significantly less during conversion process.
3. It is more efficient process.
4. It is more economical compared to other conversion techniques.

Principle of DEC

For answer refer Unit-V, Q14, Topic : Principle of DEC.

Q16. What are the two statements known as the carnot principle

Answer : May-17, (EEE), R13, Q10(a)

1st Carnot Principle

It states that "the efficiency of reversible heat engine is always higherthan the irreversible heat engine,when both are operating between same thermal reservoirs".

2nd Carnot Principle

It states that "all reversible heat engines operating between the same themal reservoirs will have the same efficiency".

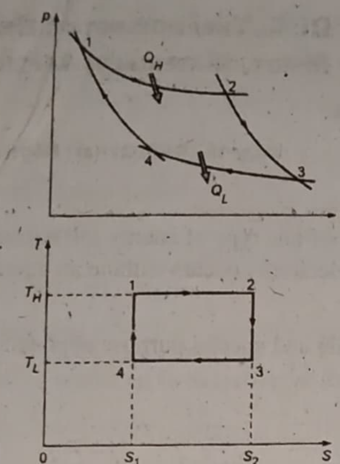
Q17. Explain the carnot cycle

Answer : June-18, (R13), Q10(a)

The Carnot cycle was proposed by a french engineer, Sadi Carnot in 184. This cycle is also called as reversible cycle, and it is comprises of four reversible processes. They are,

1. Reversible isothermal expansion (Process 1-2)
2. Reversible adiabatic expansion (Process 2–3)
3. Reversible isothermal compression (Process 3 – 4)
4. Reversible adiabatic compression (Process 4 –1)

The above process can be shown in thermodynaic cycle on PV and Ts diagrams as shown in below figure.



Figure

Working Principle of Carnot Cycle Engine

1 **Reversible Isothermal Expansion (Proces 1 – 2)**

In this process, the heat is added to the workng medium at constant temperature T_H, and the workg medium (gas) expands slowly from state 1 to state 2 othermally.

2. **Reversible Adiabatic Expansion (Proces 2 -3)**

In this process, the gas expands graduallyn adiabatic manner, and simultaneously does the work on the surroundings until the temperature reduceso T_L.

3. **Reversible Isothermal Compression (Prcess 3 – 4)**

During this process, the gas is compressed b an external force, and the temperature of the gas is maintained at constant value by rejecting the heat continously to the heat sink.

4. **Reversible Adiabatic Compression (Proess 4–1)**

In this process, the gas is compressed adiabtically from sate 4 to state 1.

The efficiency of the Carnot cycle is giverby,

$$\eta_{th} = \frac{\text{Net workdone}}{\text{Heat supplied}} = \frac{W_{net}}{Q_H}$$

$$\eta_{th} = 1 - \frac{T_L}{T_H}$$

Q18. Elaborate the seebeck, peltier, Joule and Thomson effects with the practical aplications.

Answer :

1. **Seebeck Effect**

Consider two dissimilar metals are joined ogether in the form a loop such that there are two junctons. When a temperature difference is maintained between these two junctions, an electric current (e.m.f) will flw around the loop. This phenomenon is known as seebck effect.

The principle of seebeck effect is illustrated in below figure.

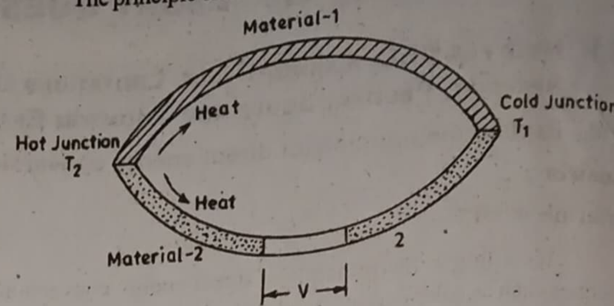


Figure (1)

The magnitude of current depends on the materials used and the temperature difference between the junctions (i.e., $\Delta T = T_2 - T_1$).

The magnitude of e.m.f is given by,

$$V(\text{or})E = \alpha_s \Delta T$$

Where,

α_s – seebeck coefficient

ΔT – Temperature difference between hot and cold junctions.

Applications

Seebeck effect is used in 'thermocouples' to measure the temperature, and in thermoelectric generation for power generation.

2. **Paltier Effect**

When an electric current flows across an isothermal junction formed because of two dissimilar materials, there is either an evolution or absorption of heat at the junction. This phenomenon is known as the 'peltier effect'.

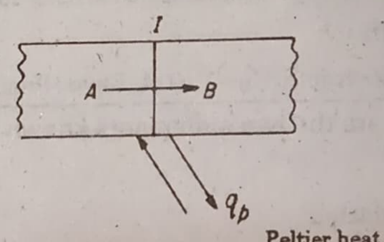


Figure (2)

Since the peltier effect is a reversible effect, the heat is evolved when current flows in one direction and the same amount of heat is absorbed at the junction if the current flows in reverse direction.

Peltier Coefficient $(\alpha_{P_{1-2}})$: It is defined as the heat evolved or absorbed at the junction per unit current flow per unit time,

i.e., $\alpha_{P_{1-2}} = \alpha_{P_1} - \alpha_{P_2} = \frac{Q_P}{I}$

Then, $Q_P = \alpha_{P_{1-2}} \times I$

Where,

I – Peltier heat per unit time

Q_P – Peltier heat

Applications

Peltier effect is used in cooling and heating applications such refrigeration and air conditioning, IC cooling, etc.

3. **Joule Effect**

Joule effect states that when a current (I) flows through a resistance R, heat (Q) is generated by the resistance and is equal to I^2R.

i.e., Joulean heat $Q = I^2R$

The conversion of electric energy into heat is irreversible

Applications of Joule Effect

Applications of Joule effect are found in electrical devices such as electric iron, electric toaster, and electric heating, etc.

4. **Thomson Effect**

When an electric current flows through a material having temperature gradient (i.e., temperature difference between two points), there is an evolution or absorption of heat depending upon the material. This phenomenon is called 'Thomson effect'. The Thomson effect is schematically shown in below figure.

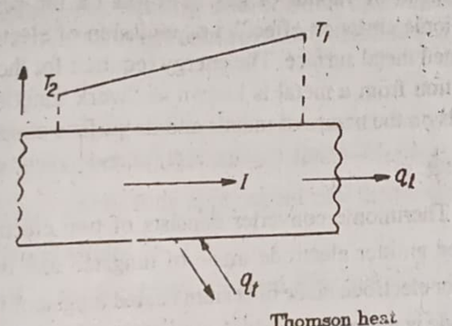


Figure (3)

The Thomson heat is reversible, since the direction of heat transfer can be reversed with out change in magnitude by reversing the direction of current low.

Thomson Coefficient (σ)

It is defined as Thomson heat absorbed or evolved per unit time per unit electric current and per unit temperature gradient.

$$\text{i.e., } \sigma = \frac{d\frac{Q_T}{d_x}}{\frac{dT}{dx}}$$

Where,

$\frac{dQ_T}{dx}$ – Heat interchange per unit time per unit length of conductor

$\frac{dT}{dx}$ – Temperature gradient.

Therefore, the Thomson heat per unit time is given by,

$$\frac{dQ_T}{dx} = \sigma I \frac{dT}{dx}$$

The Seebeck, Peltier and Thomson effects are more commonly observed in semiconductors compared to metals.

Applications of Thomson Effect

Applications of Thomson effect found semi conductors.

Q19. Explain (i) Seebeck (ii) Peltier and (ii) Joule Thomson effects.

April-18, (ME), (R1), Q11(a)

Answer :

For answer refer Unit-V, Q18, (Excluding applications).

Q20. Explain the concept of joule Thompson efect and its applications.

May-17, (ME), (R13), Q1(a)

Answer :

For answer refer Unit-V, Q18, Topics: Joule Effect ad Thomson Effect.

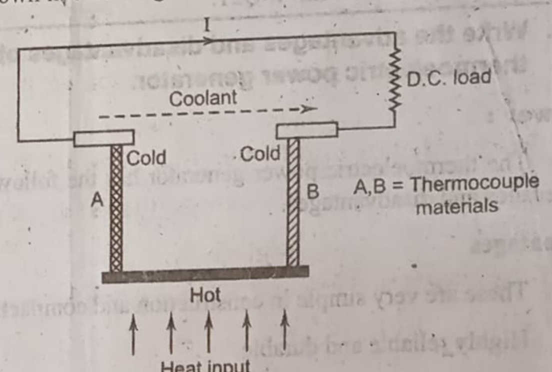
Q21. Describe briefly the working of a thermoelectric generator.

May-19, (R15), Q10(b)

Answer :

Thermoelectric generator is a device that converts the heat energy directly into electrical energy by using the 'seebeck effect'. It is very simple DEC device but the efficiency is very low of the order of 1%. to 3%. The efficiency of the thermoelectric generator depends upon the temperatures of the hot and cold junctions.

A simple arrangement of thermoelectric power generator is shown in below figure.



Figure

As shown in figure, the thermocouple materials A and B are joined at the hot end, and the other ends are kept cold. Then an electric current or electromotive force is generated due to the between the cold ends due to the temperature difference. This direct current (DC current) will flows in a circuit or through an external load connected between these ends. The flow of current will be continuous until the heat is supplied at the hot junction (generally, solar energy is supplied) and removed from the cold ends by using cold water. The voltage and power output of any thermocouple can be increased by increasing the temperaure difference between the hot and cold ends.

The net useful power output of the thermoelectric power generator is given by,

$$W = I^2 R$$

Where,

I – Current in amp (A)

R – Extremely load resistance (Ω)

The current in the circuit is given by,

$$I = \frac{\alpha \Delta T}{(R_i + R)}$$

Where,

α – Seeback coefficient

ΔT – Temperature difference between hot and cold junctions

R_i – Internal resistance of thermoelectric generator

In practical thermoelectric converter, number of thermocouples are connected in series to increase both voltage and power output.

Q22. Explain the principles of Direct Energy Conversion and with the help of line diagram, explain the working details of thermoelectric generator.

Answer : April-18, (EEE), (R13), Q10

Principle of Direct Energy Conversion

For answer refer Unit-V, Q14, Topic: Principle of DEC.

Working of Thermoelectric Generator

For answer refer Unit-V, Q21.

Q23. Write the advantages and disadvantages of thermoelectric power generator.

Answer :

The thermoelectric power generator has the following advantages and disadvantages.

Advantages

1. These are very simple in construction and compact.
2. Highly reliable and durable.
3. Since there are no moving parts used, it is free form noise.
4. It requires minimum maintenance.
5. Since it is portable, can be used for remote and space applications.
6. It uses low grade thermal energy.

Disadvantages

1. The output is low
2. The efficiency is low
3. The cost is high

Q24. Describe the operation of a thermionic converter.

Answer : Model Paper, Q11(a)

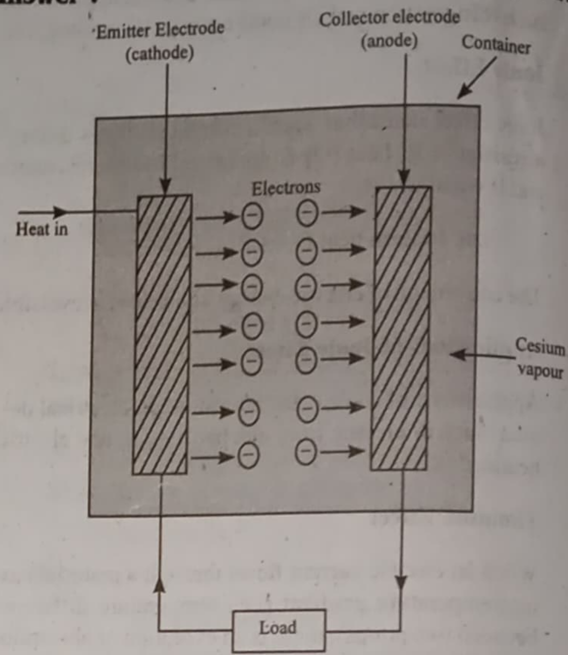


Figure : Thermionic Converter

In a thermionic convertor, electrons will act as a working fluid instead of vapour or gas. It works on the principle of "thermionic emission effect", i.e., emission of electrons from the heated metal surface. The energy required for the emission of election from a metal is known as "work function" which depends on the nature of metals and its surface conditions.

Working

Thermionic converter consists of two electrodes, one is called emitter electrode made of tungsten and the other is collector electrode made of cesium coated tungsten. The emitter electrode is maintained at higher temperature. Hence, its work function value is high. Whereas the work function value of collector electrode is less. These two electrodes are placed in a container which consists of ionised gas or cesium vapour to avoid or reduce "space charge". On heating the emitter electrode, electrons are emitted and move towards collector electrode, which becomes negatively charged. This movement of electrons will lead to development of a electromotive force (voltage) between the two electrodes. Hence, direct electrode current flows through the external circuit.

In thermionic converter, more power can be obtained by,

1. Maintaining the emitter electrode's temperature of to 1000°C.
2. By coating the collector electrode with solid cesium. This will reduce the work function of the electrode and increases the output power.

Efficiency of 40% can be obtained with higher temperature of the emitter electrode.

Q25. Explain briefly about the 'figure of merit'

Answer :

The 'figure of merit' is an index used in rating thermoelectric converters. It is denoted by 'Z'.

For a single material,

$$Z = \left[\frac{\alpha_{SA} - \alpha_{SB}}{\sqrt{\rho_A k_A} + \sqrt{\rho_B k_B}}\right]^2$$

The 'figure of merit' depends on the thermoelectric material properties. The material having large see back coefficient, small thermal conductivity and small electrical resistivity, results in higher value of 'Z'.

The quality of the thermocouple increases with the value of Z.

Q26. List various thermoelectric materials used.

Answer :

The following materials are widely used in thermoelectric materials.

	Material	Formula	Figure of merit, $Z(°K^{-1})$
1.	Lead telluride	PbTe	1.5×10^{-3}
2.	Bismuth telluride (doped with Sb or Se)	$Bi_2 Te_3$	4×10^{-3}
3.	Germanium telluride (with bismuth)	GeTe	1.5×10^{-3}
4.	Cesium sulphide	CeS	1.0×10^{-3}
5.	Zinc antimonide (doped with silver)	Zn Sb	1.5×10^{-3}

Q27. Explain the heating and cooling applications of a thermoelectric system comment on the materials used for low and high temperature applications.

June-18, (R13), (a)

Answer :

Thermoelectric coolers and heaters are some times called as thermoelectric modules. These are solid state devices (i.e., no moving parts are present) that convert electrical energy into heat energy (i.e., temperature gradient) based on the "peltier effect".

Cooling and heating applications of a thermoelectric system are as follows.

1. **Refrigeration :**

   Used in small refrigerators and mini in-vehicle refrigerators.

2. **Air Conditioning**

   Used in air conditioning systems for zonal climate control, i.e., controlling the climate where it is needed, thus, the operating cost can be reduced.

3. **Thermal Comfort**

   Thermoelectric systems are used for providing thermal comfort in following purposes.

   (i) Heated and cooled mattresses

   (ii) Heated and cooled vehicle seats

   (iii) Heated and cooled office chairs

Thermal Convenience

Used for beverage heating and cooling, and also used in wine bottle coolers.

Electronics Cooling

Thermoelectric system are used in following electronic cooling applications.

(i) Electronics and CPU cooling.

(ii) Kiosk cooling

(iii) Telecom cooling devices

(iv) Battery thermal management.

Thermoelectric Materials

The thermoelectric materials are mainly three types based on their working temperatures.

1. **Bismuth Telluride (Bi_2Te_3) Alloy :** This material is a type of semiconductor. It is best suited for thermoelectric refrigeration with working temperatures less than 450°C.

   It has high electricity conductivity, but the heat transfer capability is low.

2. **Lead Telluride (PbTe) Alloy :** This material is extremely toxic, generally causes water pollution, and also damages respiratory organs, skin and stomach in humans. It has a melting point of 905°C. It is used for thermoelectric generator and it is suitable for working temperatures around 1000°C.

3. **Silicon – Germanium Alloy :** This material is a type of semiconductor, mostly used for thermoelectric generator. The optimum working temperature is about 1300°C.

Q28. Explain about the applications of thermoelectric generators.

Answer : July-19, (R15), Q11(a)

The thermoelectric generators have following applications.

1. **Nuclear Reactor With Thermoelectric Fuel Elements**

The thermoelectric generators can be incorporated in the fuel elements of the nuclear reactor as shown in below figure.

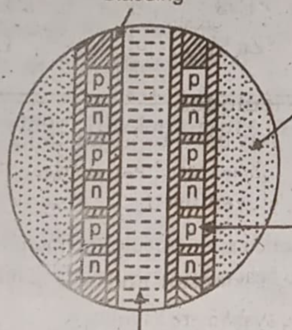


Figure (1)

With the use of thermoelectric generator, large power outputs can be obtained in nuclear reactors.

2. **Combined Thermoelectric And Steam Power Plant**

The thermoelectric generator can be u[illegible]ping plant to a steam power plant, which increases the source temperature to a great extent. Therefore, the overall efficiency of the combined plant will increase. The schematic diagram of the combined thermoelectric and steam power plant is shown in below figure.

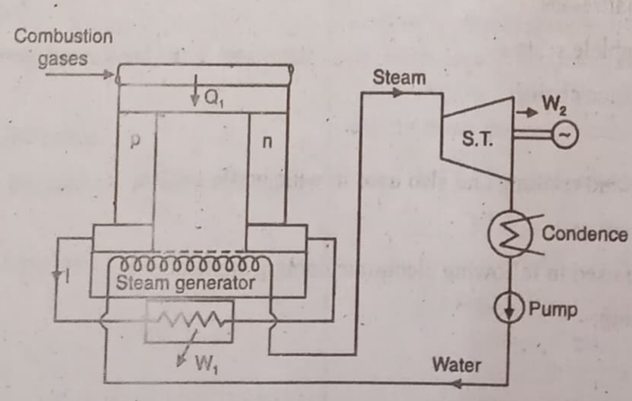


Figure (2)

3. **Thermoelectric Waste Heat Stack**

Thermoelectric generators can be used to produce electricity by using the waste heat from gas turbines, diesel engines and the exhaust (or) stack gases. The schematic diagram of the use of thermoelectric generators is shown in below figure.

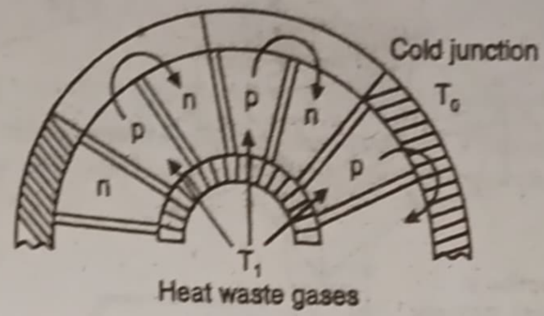


Figure (3)

As shown in figure, the metal stack consists of a series of rings made of two different materials connected at the inner and outer annular edges alternately.

4. **Decay Heat of Radioactive Isotopes**

Small thermoelectric generators are used for converting the decay heat of radioactive isotopes into electricity. Radioisotope thermoelectric generators (RTGs) are used in space applications for power generation in satellites, spacecrafts, etc.

5. **Electricity From Solar Energy**

Thermoelectric generators are used along with the solar collectors to generate electricity from the solar energy.

5.2 MHD Generators, Principles, Dissociation and Lonization, Hall Effect, Magnetic Flux, MHD Accelerator, MHD Engine, Power Generation Systems, Electron Gas Dynamic Conversion, Economic Aspects

Q29. Explain the working details of MHD accelerator May-17, (ME), (R13), Q10(b)

OR

Explain the principle of MHD power generation.

Answer : [May-13, (R09), Q8(b) | Model Paper, Q10(b)]

The principle of MHD power generation is the Faraday's law of electromagnetic induction. It states that, when an electric conductor passes across a magnetic field a voltage is induced in the conductor which produces an electric current. The MHD power generator uses a gaseous conductor i.e., an ionised gas instead of solid conductor. The ionised gas is passed through a powerful magnetic field at a high velocity, which generates the current. This current is extracted by mounting the electrodes that are placed at an appropriate position in the stream of ionised gas. The MHD generator produces d.c. power directly. The arrangement and principle of MHD generator is schematically shown in below figure.

Consider an electric conductor, that is moving through the magnetic field. Then, the conductor experiences a retarding force, and an electric field is induced which produces current according to the Faraday's law of electromagnetic induction.

The induced emf is given by,

$$E_{ind} = \text{Velocity of conductor} \times \text{Magnetic field intensity}$$

$$\vec{E}_{ind} = \vec{u} \times \vec{B}$$

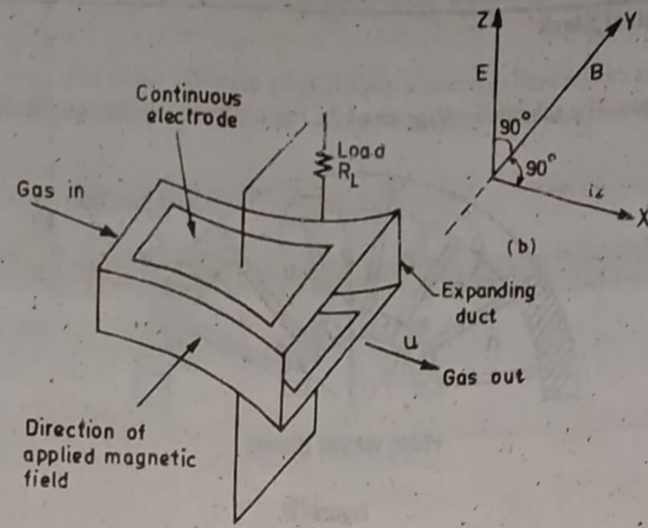
The current density is given by,

$$J = \text{Electrical conductivity} \times \text{emf induced}$$

$$\vec{J}_{ind} = \vec{\sigma} \times \vec{E}_{ind}$$

The retarding force experienced by the conductor is the Lorentz force, and is given by,

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



Figure

Q30. What is the principle of MHD power generation and discuss about the main parts of an MHD generator?

Answer :

April-18, (ME), (R13), Q10(b)

Principle of MHD Power Generation

For answer refer Unit-V, Q29.

Parts of MHD Generator

The main parts of the MHD generator are as follows,

1. **MHD Duct**

   The high temperature ionised gas flows through this duct at a very high velocity.

2. **Magnetic Field**

   The magnetic filed is produced by some appropriate coils, and its direction is at right angles to the gas flow.

3. **Electrodes**

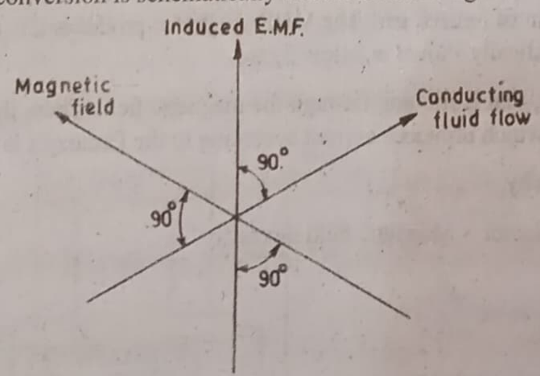
   The electrodes are placed at suitable locations to carry the current to external loads in the Faraday and Hall configurations.

Q31. Explain the principle of magneto hydrodynamic conversion.

Answer :

Magneto hydrodynamic conversion (MHD) is an energy conversion technique in which, the kinetic energy of an eclectically conducting fluid (a gas or a gas combination) when flows through a stationary magnetic field is directly converted into electrical energy.

The basics principle of MHD conversion is schematically shown in below figure.



Figure

As shown in the figure, when the direction of flow of the electrically conducting fluid is perpendicular to the direction of magnetic field, an electromotive force or electric voltage is induced in the direction perpendicular to both conducting fluid flow and magnetic field directions.

Q32. Explain about (i) MHD accelerator (ii) MHD engine.

Answer :

July-19, (R15), Q10(b)

(i) **MHD Accelerator**

For answer refer Unit-V, Q29.

(ii) **MHD Engine**

MHD engine is proposed as a single flow path alternative to current turboramjet engines used in space applications. Consider a hypersonic airbreathing engine of a ramjet or scramjet type that is augmented with an MHD energy management system. This engine uses the MHD bypass energy concept. The various components of the engine is shown in below figure.

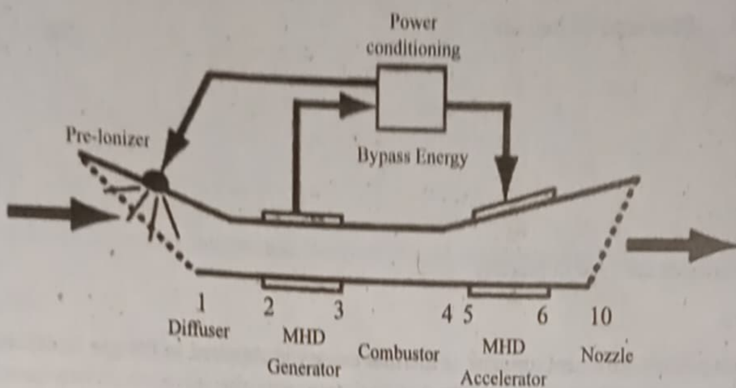


Figure (1) : Hypersonic Air-breathing Engine with MHD Energy Bypass System

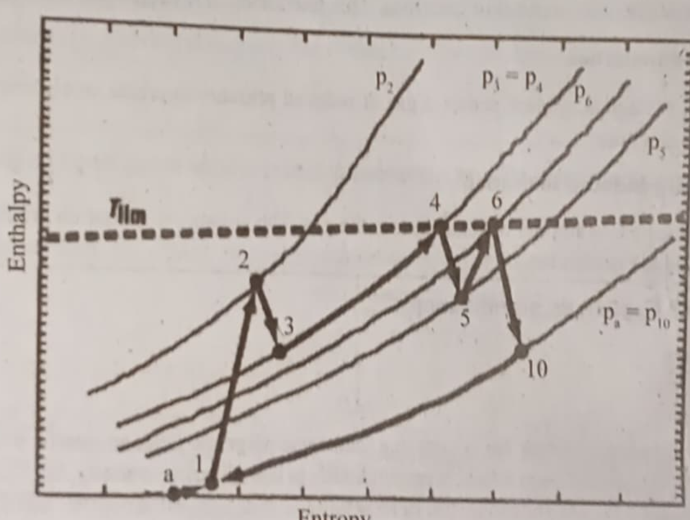


Figure (2) : Ts Diagram

As shown in the figure, the description of each process is as follows,

Process (a - 1) : Air pre-ionisation and heat addition

Process (1 - 2) : Adiabatic compression and flow deceleration

Process (2 - 3) : MHD conversion of total enthalpy to electrical power and deceleration of the flow.

Process (3 - 4) : Constant static pressure and frictionless heat addition.

Process (4 - 5) : Adiabatic expansion to maintain the temperature inside the accelerator in design limits.

Process (5 - 6) : MHD conversion of electrical power to total flow enthalpy and acceleration of the flow.

Process (6 - 10) : Adiabatic expansion and acceleration of the exhaust flow.

The MHD engines are capable of extending the operating range of turbojets to the Mach number 7 for sustained hypersonic flight.

Q33. Explain the principle of dissociation and ionization with respect to MHD.

Answer :

April-18, (ME), (R13), Q10(a)

Ionisation is the process in which the electrons are removed from an atom. This process is employed to increases the conductivity of the working fluid used in MHD systems to a required level.

The electrical conduction occurs due to the movement of the free electrons and positive ions under the effect of a magnetic field. The following are various ionisation methods.

1. Thermal ionisation
2. Magnetically induced ionisation
3. Radio frequency wave induced ionisation
4. Photo ionisation
5. Radioactivity
6. Radioactivity
7. Flames

However, only first three methods are used in practice.

1. **Thermal Ionisation**

In this method of ionisation, sufficient amount of thermal energy is supplied to the gas to achieve ionisation. With the increase of temperature of the gas, the kinetic energy of its constituents also increases. When the temperature is increased to a sufficiently high value, then the electron gets the ability to ionise a molecule with which it collides. These electron molecule collisions produce more number of electrons. This phenomenon is called thermal ionisation.

2. **Magnetically Induced Ionisation**

In this method, a d.c. voltage is applied across a gas at reduced pressure to create an electric field. This electric field supplies energy to the electrons.

3. **Radio Frequency Wave Induced Ionisation**

This method can produce a low amount of ionisation in the gas. The amount of ionisation produce by this method is not sufficient enough for MHD generation.

Q34. What is Hall effect? Explain its significance.

Answer :

Hall Effect

When a current carrying semiconductor bar is kept in a transverse magnetic field, an electric field is produced within the semiconductor. The direction of generated electric field is perpendicular to both the current and applied magnetic field. This process is referred to as Hall effect. Due to the generated electric field, a voltage is developed across the surfaces of semiconductor bar known as Hall voltage.

$$R_H = \frac{1}{ne} = \frac{-1}{\rho} \quad [\because \rho = -ne]$$

Significance

1. **Determination of Type of Semiconductor**

The sign of the Hall coefficient depends on the type of semiconductor placed in the transverse magnetic field. Hall coefficient is negative for an n-type semiconductor and positive for a p-type semiconductor. Therefore, the sign of the Hall coefficient is used to determine whether a given semiconductor is n or p-type.

2. **Calculation of Carrier Concentration**

Concentration of the carrier inside the semiconductor bar placed in the magnetic field can be determined using the expression.

$$n = \frac{1}{e} R_H = \frac{1}{e} \frac{V_H b}{I_x B}$$

Where,

B – Magnetic flux density in Wb/m^2

I_x – Current flowing through the semiconductor bar

b – Width of the bar

V_H – Hall voltage

The Hall voltage 'V_H' is measured by placing two probes at the centers of the top and bottom surfaces of the semiconductor bar.

3. **Determination of Mobility**

Assuming that the flow of current in the n-type semi conductor bar placed in the magnetic field is only due to majority carries, that is electrons,

$$\sigma = ne\mu_n$$

$$\Rightarrow = \mu_n = \frac{\sigma}{ne} = \sigma R_H$$

Since, $R_H = \dfrac{V_H b}{I_x B}$

$$\therefore \quad \mu_n = \sigma\left(\frac{V_H b}{I_x B}\right)$$

If σ is known the mobility μ_n can be determined. Similarly, μ_P is determined by placing a P-type semiconductor bar i the magnetic field.

4. **Hall Effect Multiplier**

If the magnetic field 'B' (in which the semiconductor bar is placed) is produced by an air core coil carrying a current I' through it,then B is proportional to I'. The Hall voltage which is a product of B and I, (I is the current flowing through the bar) will now be a product of I' and I. This forms a basis of the multiplier.

5. **Determination of Magnetic Flux Density**

The Hall voltage V_H is directly proportional to magnetic flux density, of a semiconductor. Hence, B is calculated using the formula,

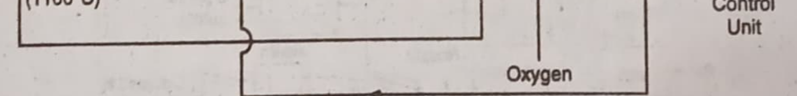
$$B = \frac{V_H b}{I_x R_H}$$

Q35. Explain the working of open cycle MHD system generation and its advantages and limitations.

April-18, (EEE), (R13), Q11

Answer :

The schematic diagram of open cycle MHD power generation system is shown in below figure.



Figure

This system consists of the following main components.

1. **Combustion Chamber**

The fuels like coal, oil or natural gas are burnt with the preheated or hot compressed air in the combustion chamber. The compressed air must be preheated to at least 1100°C before supplying to the combustor. The high temperature and high pressure gases are produced due to the combustion process. Then the seeding material (cesium or potassium) is injected and mixed with the not gases to increase the electrical conductivity of the gases. Potassium carbonate is the most commonly used seeding material. The not pressurised gases, known as working fluid leaves the combustor and flows through the convergent- divergent nozzle. Thus, the working fluid coming out from the nozzle enters the MHD generator at a high speed.

2. **MHD Generator**

The MHD generator is a divergent channel or duct which is made of a heat resistant alloy such as Inconel, with external water cooling. The direction of magnetic field is perpendicular to the direction of the motion of hot gases. A number of electrode paris are placed in the duct at suitable location to conduct the electricity produced to the external load. The d.c power is converted into a.c power by using an inverter.

3. **Preheater**

The temperature of the hot gases falls to 1900°C after producing electricity. These gases enters the gas preheater, where oxygen or oxygen enriched air or compressed air is heated to a temperature of 1100°C. This preheated air is used to produce the working fluid at a temperature range of 2300°C to 2700°C to 2700°C in the combustion chamber.

4. **Seed Recovery Unit**

In seed recovery unit, the seeding material is recovered for reusing purpose. Due to the presence of sulphur in the fuel, the potassium carbonate is converted into potassium sulphate. During recovery process,the potassium sulphate is converted back to potassium carbonate by desulfurization method.

5. **Hot Gases**

The got gases from the seed recovery unit are passed through pollution control device to remove sulphur and nitrogen oxides before releasing into the atmosphere through the chimney.

Advantages and Limitations of MHD System Generation

For answer refer Unit-V, Q38.

Q36. Describe MHD closed cycle system, with its advantages and disadvantages. May-19, (R15), Q10(a)

OR

With the help of a diagram explain the operation of closed cycle MHD generating system.

Answer : June-18, (R13), Q10(b)

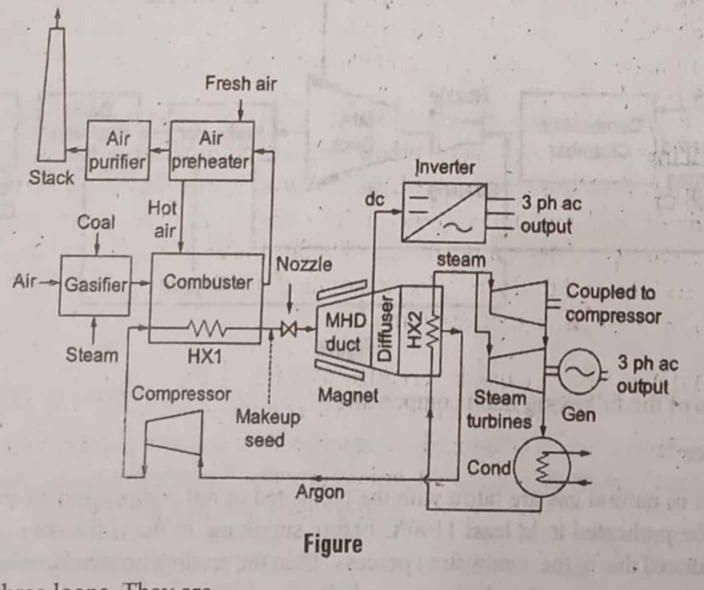
The closed cycle MHD power generation system are of two types.

1. Seeded inert gas system
2. Liquid metal system

Seeded Inert Gas System

The seeded inert gas system works on Brayton cycle with inert carrier gas (either argon or helium). Similar to open cycle MHD systems the electrical conductivity is maintained in the working fluid by the ionisation of a seed material.

The schematic diagram of a closed cycle seeded insert gas system is shown in below figure.



Figure

This system consists of three loops. They are,

1. **Combustion Loop**

It is an open loop, in which the cola is gasified and burns in the combustor. The flue gases are made to pass through the primary heat exchanger (H 1), air preheater and air purifier and then released into the atmosphere.

2. **Argon Loop or MHD Loop**

In MHD loop, the seeded inert gas, either argon or helium is compressed in a compressor and it is heated by passing through the primary heat exchanger. Then, a small amount of seed material is added to compensate the loss of seed material through leakages. The cesium metal is sued as seed material in this system. It is expensive than potassium, but it provide sufficient conductivity at a relatively lower temperature of about 1900°C. Due to lower operating temperatures, this system allows the use of variety of materials for different equipment. But the efficiency of the cycle reduces due to lower operating temperature. The d.c electricity available form the MHD generator is converted to a.c electricity by using an inverter, and then fed into the grid.

3. **Steam Loop**

This loop is used for further recovery of the heat of working fluid and converting this heat into electrical energy through a waste heat boiler known as secondary heat exchanger, turbine and generator. Some amount of this electrical energy used to rn the argon cycle compressor through a steam turbine.

Advantages and Disadvantages of MHD system

For answer refer Unit-V, Q38.

Q37. Discuss briefly about liquid metal MHD system with a neat sketch.

Answer :

In this system, a liquid metal provides the electrical conductivity, and the carrier gases are inert gases like argon and helium. The combustion chamber is provided with an heat exchanger internally, which is used to pressurize and heat the carrier gas. This heated and pressurized gas is incorporated into the liquid metal, usually hot sodium to form the working fluid. The working fluid is passed into the MHD generator through a nozzle. Then the carrier gas supplies the high directed velocity of the electrical conductor (i.e., the liquid metal).

After passing through the generator, the liquid metal is separated from the carrier gas. The remaining heat in the gas is passed to the water in the secondary heat exchanger to obtain steam for operating the turbine generator. The schematic diagram of a closed cycle liquid metal system is shown in below figure. Finally, the gas is cooled, compressed and returned to the combustion chamber for reheating and mixing with the recovered liquid metal.

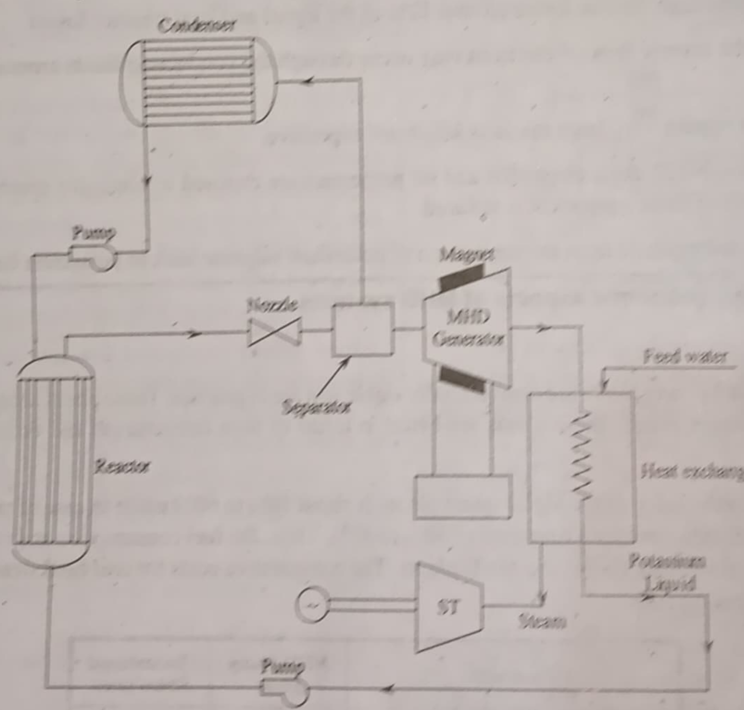


Figure: Closed Cycle MHD Generator using Liquid Metal as Working Fluid Coupled with Steam Generator

As shown in the figure, liquid potassium is used as working fluid, which is heated in a breeder reactor and passed through a nozzle to increase its velocity. The vapour formed due to nozzle action is separated in the separator and condensed then the condensed working fluid is pumped back to the reactor. The liquid that comes out from the separator is passed through the MHD generator to produce D.C power. The liquid potassium coming out of the MHD generator is allowed to pass through the conventional steam plant. The heat of the liquid potassium is used in the heat exchanger to produce the steam, which is utilized to run steam turbine generator, thus producing electricity.

Q38. Write the advantages and disadvantages of MHD systems.

Answer :

Advantages

The advantages of MHD system are as follows.

1. The conversion efficiency can be around 50%, while the most efficient steam plants having 40% conversion efficiency.
2. Since it has no moving parts, it is more reliable.
3. It generates large amount of power.
4. The power produced by the closed cycle MHD system is free of pollution.
5. As soon as it is started, it can able to reach the full power level.
6. Compared to conventional fossil fuel plants, the size (m^2/kw) of the MHD plants is significantly less.
7. The overall operational costs are about 20% less than that of conventional steam plants.
8. The capital costs of MHD plants are comparable to that of conventional steam plants.
9. Due to direct conversion of heat into electricity, the use of the gas turbine or both gas turbine and boiler is eliminated. Thus, the energy losses are reduced.
10. The MHD system has the advantages of better fuel utilisation.
11. It is suitable for peck power generation.

Disadvantages

The MHD system have the following disadvantages.

1. The MHD system has high friction losses (About 12% of the input) and heat transfer losses.
2. In MHD systems,the reverse flow of electrons may occur through the conducting fluids around the ends of the magnetic field.
3. The MHD systems require very large magnets which are expensive.
4. Since the combustor, MHD duct, electrodes and air preheaters are exposed to corrosive combustion gases at very high temperatures the life of these equipment is reduced.
5. The separation of seed material from the conversion of potassium sulphate back to potassium carbonate is a difficult task.

Q39. Discuss about the economic aspects of MHD systems.

Answer :

Coal fired MHD steam power plants are commercially viable and are in practice. These plants setup against the conventional coal fired steam thermal power plants, these plants are better in terms of both environment and economics over conventional steam thermal plants.

The overall thermal efficiency of the MHD steam plants is about 50% to 60% while in case of most efficient conventional steam thermal plants, the efficiencies are in the range of 30% to 40%. Thus, the fuel consumption and emission would be reduced by 15% to 25%, this is the rain advantages of the MHD plants. The comparative costs for coal fired steam thermal plant and MHD steam plants are shown in below table.

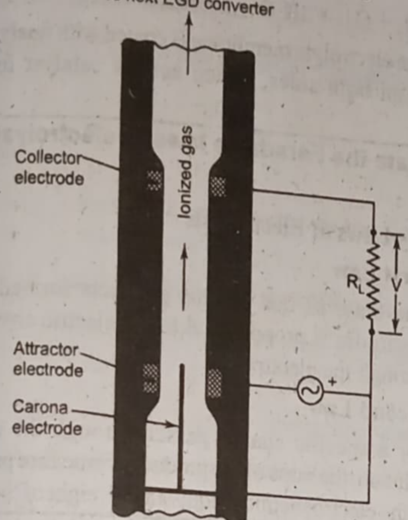
Particular	*MHD-Steam Plant*	*Conventional Steam plant*
Total cost of installation \$/kW, (1990 Base)	1880	1840
Thermal Efficiency of Plant	46%	32%
Fuel Costs \$/kWh	0.002	0.0028
Cost of Electricity \$/kWh	0.059	0.062

Though the MHD power plants are preferable over conventional steam plants, they have some technological problems related with design, materials selection, high temperatures, reliability, service life, etc.

Q40. What is meant by Electron gas dynamic conversion and where do you use this principle?

Answer : May-17, (ME), (R13), Q11(b)

The Electron Gas Dynamic generator (EGD), in which the potential energy of a high pressure gas to carry the electrons from low potential electrode to a high potential electrode,thereby doing work against the electric filed. The constriction and working principle of EGD is shown in below figure.



Figure

As shown in the figure the EGD consists of a duct that is electrically insulated, corona electrode, attractor electrode, collector electrode, ionised gas and an external load.

The corona electrode placed at the entrance of the duct produces electrons. Then this ionised gas particles are carried down the duct with the neutral atoms. The collector electrode located at the end of the insulated duct neutralise the ionised particles. The most commonly used working fluids in EGD are, either combustion gases produced by burning of fuel at high pressures or pressurised reactor gas coolant. The maximum power output per the channel from EGD is about 10 to 30 W.

Thus, to obtain required amount of power output, several thousand channels are connected in series and parallel. The voltage produced is very high, in the order of 100000 to 200000 V. Thus, the EGD converter requires high voltage insulators like Beryllium oxide.

The efficiency of EGD is equal to MHD steam combination.

The EGD system has following advantages over MHD systems.

1. EGD systems can be operated at relatively low temperatures.
2. Injection and recovery of seed material is not required.
3. Large quantities of condenser cooling is not required.
4. Since EGD doe not need a steam generator, it is self contained.
5. Energy can be extracted till the gases reach almost the stack temperature.

5.3 Fuel Cells, Principle, Faraday's Laws, Thermodynamic Aspects, Selection of Fuels and Operating Conditions

Q41. With the help of a diagram, explain the operation of a fuel cell. July-19, (ME), (R15), Q10(a)

OR

Explain the principle of operation of an alkaline fuel cell with the aid of a diagram.

April-18, (ME), (R13), Q11(b)

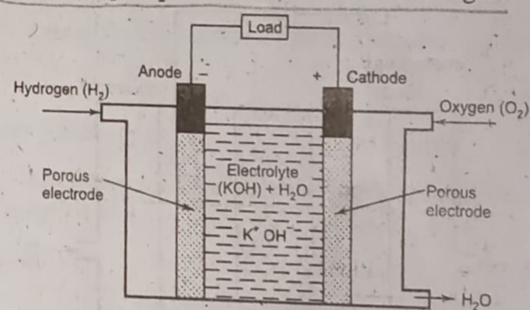
OR

Draw the line diagram and explain the working of hydrogen fuel cell.

Answer : [May-17, (ME), (R13), Q11(a) | Model Paper, Q11(b)]

Alkaline fuel cell was invented by a British scientist, Francis Thomas Bacon. Thus, this fuel cell is also known as Bacon's fuel cell or hydrogen -oxygen fuel cell.

In this cell, hydrogen is used as fuel and oxygen is used as oxidant, since these two elements are highly reactive with least complications. The potassium hydroxide (20% to 40% concentration) is used as the electrolyte, which has high electrical conductivity and is less corrosive than acids. The construction $H_2 - O_2$ fuel cell is shown in below figure.



Figure

Hydrogen-oxygen cell consists of three chamber, which are separated by two porous nickel electrodes (anode and cathode). The middle chamber i.e., space between the two electrodes is filled with the aqueous solution of potassium hydroxide (KOH). The surfaces of the electrodes are treated with chemicals, so that the electrodes repel electrolytes. As a result, the leakage of potassium hydroxide into the outer chamber is minimised.

The fuel (i.e., hydrogen) is supplied to anode, it gets oxidized and releases H^+ ions. Free electrons flow through the external circuit form anode to cathode, which generates the electricity. Hydrogen ions (i.e., H^+ ions) combine with the OH^- ions in the electrolyte solution to form four water molecules. Oxygen (O_2) is fed into the fuel cell at cathode, where it combines with the four electrons from the external circuit, and react with water present in the electrolyte to form (OH^-) ions These OH^- ions remain in the electrolyte to combine with incoming Hydrogen molecules. Thus, the electrolyte remains unchanged in terms of quantity and chemical composition.

The reaction are as follows,

$$4KOH \rightarrow 4K^+ + 4(OH)^-$$

At Anode

$$2H_2 \rightleftharpoons 4H^+4e^-$$
$$4H^+ + 4OH^- \rightleftharpoons 4H_2$$
$$\overline{2H_2 + 4OH^- \rightleftharpoons 4H_2 + 4e^-}$$

At Cathode

$$O_2 \rightleftharpoons 2O^-$$
$$2O^- + 2H_2O + 4e^- \rightleftharpoons 4H_2O$$
$$\overline{O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-}$$

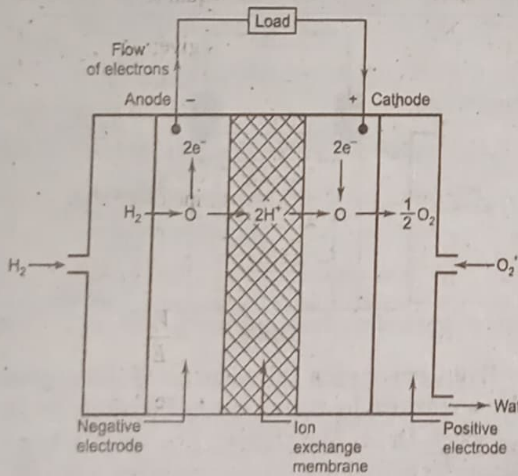
Cell Reaction

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Electrical Energy}$$

Q42. Explain the principle and working of ion exchange membranes fuel cell.

Answer :

The ion exchange membrane fuel cell is also called as polymer electrolyte membrane fuel cell (PEMFC). The schematic diagram of this cell is shown in below figure.



Figure

This cell consists of a solid electrolyte ion-exchange membrane, two electrodes and gas feed tubes (i.e., inlet and outlet sections).

The electrolyte is a solid polymer membrane of an organic material such as polystyrene sulphuric acid. This membrane allows the H^+ ions to pass through it, and is non permeable to the reactant gases, i.e., hydrogen and oxygen. In this cell, the hydrogen is used as fuel and the hydrogen ions are charge carriers. The hydrogen molecules is split into hydrogen ions and electrons at anode. These hydrogen ion pass through the electrolyte membrane and travel towards the cathode. The electrons flow through the external circuit and generates electric power. At cathode, the oxygen is supplied, and is combines with the electrons and hydrogen ions to produce water.

The cell reactions at anode and cathode are as follows,

At Anode

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

At Cathode

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$$

Overall Reaction

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Electrical energy}$$

The electrolyte membrane is coated with finely powdered platinum on both sides, which acts as catalyst for the cell reactions.

Q43. State the Faraday's laws of electrolysis.

Answer :

Faraday's Laws of Electrolysis

1. **First Law**

   The mass of the various products formed form the electrodes is proportional to the electric charge passed through the electrolyte.

2. **Second Law**

   For a specific charge passed through the electrolyte solution, the mass of the products formed are proportional to the electrochemical equivalent weight of the products.

Q44. What are the advantages and limitations of fuel cells over other direct energy conversion systems?

May-19, (R15), Q11(b)

OR

What are the advantages and disadvantages of fuel cells?

Answer :

The advantages and disadvantages of fuel cells are as follows,

Advantages

1. Conversion efficiencies i.e. are high (approximately 70%).
2. Transmission of power is not required because they can be installed near the use point.
3. No noise is produced, and it is odourless.
4. Space requirement is less compared to conventional power plants.
5. No cooling water is required.
6. The operation of fuel cell can be started in less time.
7. It requires less maintenance.
8. It is simple in construction and safe.
9. The operation of fuel cells is pollution free.
10. Capacity of the fuel cells can be increased as per the demand.

Disadvantages

1. Initial cost is high.
2. Service life is less.
3. Difficult to refill the fuel cells in vehicles.

Q45. Explain about the thermodynamic aspects of fuel cells.

Answer : July-19, (R15), Q11(b)

In fuel cell, the reactants are converted into products by a chemical reaction in a steady flow process. The work is determined by combining the first and second laws of thermodynamics for a steady flow process.

Consider a steady flow process

According to the first law of thermodynamics,

$$\Delta Q - \Delta W = \Delta H + \Delta K.E. + \Delta P.E. \quad ...(1)$$

Where,

ΔQ – Heat transferred to the steady flow stream from the surrounding,

ΔW – Work done by the flow stream from entrance to exit.

ΔH – Change in enthlpy of the flow stream from entrance to exit.

ΔK.E – Kinetic energy of the stream, and

$\Delta P.E.$ – Potential energy of the stream.

$K.E.$ and $P.E.$ are usually negligible in fuel cells. Hence, the equation (1) can be written as,

$$\Delta W = \Delta Q - \Delta H \quad ...(2)$$

According to the second law of thermodynamics,

$$\Delta Q = \text{T}. \Delta S$$

From equation (1) and (2),

$$\Delta W_{\text{max}} = T.\Delta S - \Delta H \quad ...(3)$$

The gibbs free energy is given by,

$$\Delta G = \Delta H - \Delta T.\Delta S$$

Where, T is constant ...(4)

From equation (3) and (4),

$$\therefore \quad \Delta W_{max} = -\Delta G$$

Efficiency of Fuel Cell (η_{FC})

The efficiency (η_{FC}) of energy conversion of a fuel cell is defined as "the ratio of the useful work to the heat of combustion of the fuel".

$$\text{i.e., } \eta_{FC} = \frac{\Delta W_{\text{max}}}{-(\Delta H)} = \frac{-(\Delta G)}{-(\Delta H)} \quad ...(5)$$

For hydrogen-oxygen fuel cell, at 25°C,

$$\Delta G = (-237191) \text{ kJ/kg more}$$

Heat of reaction $\Delta H = (-285838)$ kJ/kg more

Therefore,

$$(\eta_{FC})_{\text{max}} = \frac{237191}{285838} \simeq 0.83 \text{ or } 83\%$$

E.M.F. of a Fuel Cell

The e.m.f. that will drive electrons through the eternal load is proportional to the change in Gibbs free energy.

$$\text{i.e., } E = \frac{-\Delta G}{nF} \quad ...(6)$$

Where,

E – Electromotive force

ΔG – Change in Gibbs free energy (J/mole)

n – Number of electrons per morel of fuel, and

F – Faraday's constant (= 96487 coulombs/mole)

From equation (5) and (6),

$$(\eta_{FC})_{\text{max}} = \frac{-h.F.E}{\Delta H} \quad ...(7)$$

The overall efficiency of 'reversible fuel cell' is given by,

$$(\eta_{FC})_{\text{max}} = \text{h}_{\text{FC}} \times \text{loss factor} \quad ...(8)$$

The power output of a reversible fuel cell (P_{rev}) is given by,

$$P_{rev} = \frac{\Delta G_{\text{max}}}{\text{Molar mass of hydrogen}} \quad ...(9)$$

The molar mass of hydrogen is equal to 2.016 kg/more.

Actual electrical power output is given by, ...(10)

$$Q = P_{rev.} - P_{actual} \quad ...(11)$$

Voltage Efficiency (η_v)

All the losses in a fuel cell may be included under voltage efficiency.

It is given as,

$$\eta_v = \frac{\text{Operating voltage}}{\text{Theoretical voltage}} = \frac{V_c}{E} \quad ...(12)$$

Where, V_c – Operating voltage of the fuel cell at a given current density.

E – Theoretical open circuit voltage (e.m.f)

Q46. Explain about the operating characteristics of fuel cells.

Answer :

V.I and P.I characteristics of a fuel cell

The various operating characteristics of a fuel cell as follows,

1. Current-Voltage (V-I) characteristics.
2. Power-Current (P-I) characteristics

1. **Current-voltage (V-I) characteristics**

The cell voltage V_c versus electrode current density I_d curve is used to evaluate the performance of a fuel cell.

The cell voltage V_c drops with increase in I_d due to 'Polarization' within the cell. Hence, this curve is also known as the polarization curve of the fuel cell.

Polarization is main reason for internal energy loss, and is measured in terms of polarization voltage V_p.

$$\Delta V_p = E - V_c \quad \text{...(1)}$$

i.e., E – E.m.f. of the cell, and

V_c – On -load voltage of the cell.

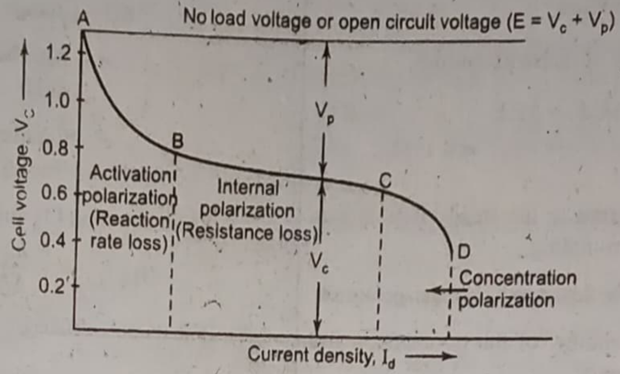


Figure (1) : V-I (V_c vs I_d) Characteristics of fuel cell

With increase in load of the cell the internal losses increase. As a result, there is a drop in the cell terminal voltage(V_c).

2. **Power-Current (P-I) characteristics**

Power per cell, $P_c = V_c \times I_C$ ...(2)

With the increase in current density, the power of a cell increases till the saturation point is reached, then it decreases due to polarization effects.

$\therefore$ Output power = Input power – Polarization losses

Efficiency of fuel cell is given by,

$$\eta_{FC} = \frac{\text{Output power}}{\text{Input power}} \quad \text{...(3)}$$

The efficiency of the fuel cell can also be calculated as follows,

$$\eta_{FC} = \frac{\text{On - load cell voltage}}{\text{No - load cell voltage}} = \frac{V_c}{E} = \frac{E - V_p}{E}$$

The power and efficiency characteristics of a fuel cell is shown in below figure.

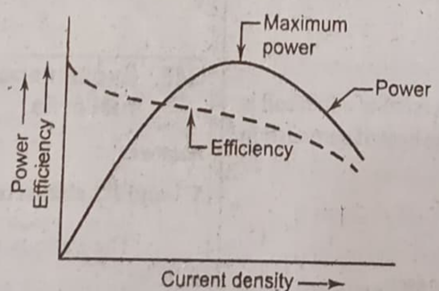


Figure (2) : Power and efficiency characteristics of a fuel cell

From the above figure, it is observed, That,

1. The efficiency of a fuel cell varies with the current density at electrode surface due to the polarization effects.
2. The power losses is converted to waste heat and released into atmosphere.

Q47. **Comment on relative performance of fuel cells.**

June-18, (R13), Q11(b)

Answer :

Relative performance various fuel cells are given in below table

Sl No.	Type of Fuel cell	Fuel	Electrolyte	Capacity [kW_e]	Efficiency [%]	Working Temperature [°C]	Applications
1.	Proton Exchange Membrane (PEM) or solid polymer	H_2, CH_4 CH_3OH	Polymer Membrane	upto 250	60 (H_2) 40 (CH_4)	60 – 80°	Cars, buses, home, CHP plants.
2	Solid oxide (SoFC)	H_2, CH_4, coal gas	$Zr(y)O_2$	10 - 25	50 – 65	800 – 1000	Domestic, small plants, CHP plants
3.	Alkaline (AFC)	Pure H_2	KOH	20	60	60 – 90	space erafts, boats
4.	Molten carbonate (M C F C)	H_2, CH_4 coal gas	Molten carbonate of Li, Na and K.	2200 (max)	48 – 60	650	Small plants, CHP plants.
5.	Direct methanal (D M F C)	CH_3OH	Polymer membrane	N.A.	40	60 – 130	Small domestic plant, CHP plants
6.	Phoothoric Acid (P A F C)	$H_2(CH_4)$	H_3PO_4	1100 (max)	40	130 – 220	Small power plants, CHP plants.
7.	Regenerative (R F C)	H_2	N. A.	N. A.	N. A.	upto 120	Domastic, CHP plants.

Q48. **Explain about the various fuels used in fuel cells.**

Answer :

The common fuels used in fuel cells are as follows.

1. **Hydrogen**

The pure hydrogen is consider as the premium fuel for all fuel cells. Pure hydrogen in combination with pure oxygen is used as the fuel in space and military applications. But, the production and storage of pure hydrogen involves high cost. As an alternative method, hydrogen rich gases can be obtained from reforming of other fuels, which is more economical.

2. **Hydrazine (N_4H_4)**

This is a liquid fuel which can be stored very easily, and it has high energy density, But, it is highly reactive, toxic and costly. This fuel can be used directly without any transformations.

3. **Ammonia (NH_3)**

It is a type of indirect fuel. Generally, it can be stored in liquid state, and it is possible to decompose catalytically at high temperature. The hydrogen produced during the decomposition process is burnt in air to provide the required heat for decomposition. If the mixture of H_2 and N_2 is used in the fuel cell, the nitrogen present in the mixture is sent out through the exhaust.

4. **Gaseous Hydrocarbons**

In case of gaseous hydrocarbons, first, the mixture of H_2 and CO is produced from hydrocarbons such as methane, propane, etc, by steam forming.

$$\text{Hydrocarbons}(CH_4, C_3H_8, \text{etc.}) \xrightarrow[\text{90°C, Ni catalyst}]{\text{steam forming at}} H_2 + CO$$

Then this mixture is used as fuel without any alterations or it is sued after the removal of CO by water gas shift reaction.

Examples : Natural gas, LPG, biogas, coal gas, land fill gas and gasified coal.

5. **Liquid Hydrocarbons**

Similar to gaseous hydrocarbons, these also first transformed to H_2 and CO by steam reforming process. Then this mixture is sued as fuel.

6. **Synthesis Gas**

Synthesis gas is a mixture of H_2 and CO in various proportions along with other impurities. These mixtures can be produced economically form both conventional and non conventional source.

(i) In MCFC and SOFC, (H_2 + CO) mixture is used as fuel.

(ii) In hydrogen fuel cells, CO is removed and H_2 content is increased by water gas shift reaction.

$$\underset{\text{(Steam)}}{CO + H_2O} \xrightarrow[\text{Cobalt molybdate catalyst}]{\text{At 400°C and 27 atm}} CO_2 + H_2 + \underset{\text{(Energy)}}{1440 \text{ kJ/kg.}}$$

(iii) In case of AFC, CO_2 present in the products is removed.

7. **Methanol**

Methanol can be used as both direct and indirect type fuel. It is transformed to a mixture of H_2 and CO with the help of steam at about 200°C in presence of catalyst.