**BATTERY TECHNOLOGY**

**1.6.1 Introduction**

Can you imagine a world without batteries? The clock on your wall requires a battery for it to work. The watch on your wrist goes on a battery. The motor vehicle needs a battery for it to start and take you to your destination. Battery is the backbone of UPS to run your computer without interruption. After a days work, if you pick-up the remote control of the television, it is again the battery that helps you to change channels of the T.V. Cameras, laptop computers, cellular phones, key chain laser, heart pacemaker and children toys – they all require batteries.

Batteries are used for so many different purposes and different applications require batteries with different properties. The battery required to start a car must be capable of delivering a large electrical current for a short period of time. The battery that powers a cardiac pacemaker must be small, rugged, leak proof, compact and capable of delivering a steady current for an extended period of time. In UPS systems, longer and consistent backup is needed. Batteries for hearing aids must be above all tiny. Batteries for torpedoes and submarines must be stable during storage and give high power for short times & certainly rechargeable. For a lap-top computer, a battery in the form of a flexible sheet distributed around the case is much preferred. Batteries remain an enormous industry with a turnover of billions of pounds worldwide.

**1.6.2 Classification of commercial cells**

**Primary Cells**: They are galvanic cells which produce electricity from chemicals that are sealed into it when it is made. This type of cells cannot be recharged as the cell reaction cannot be reversed efficiently by recharging. Once the cell reaction has reached equilibrium the cell must be discarded. No more electricity is generated and we say the battery is ‘dead’. These are also known as ‘throw – away’ batteries or irreversible batteries.

Eg: Dry cell, Lithium copper sulfide cell

**Secondary cells:** A secondary cell is rechargeable by passing current through it. In the charging process, an external source of electricity reverses the spontaneous cell reaction and restores a non- equilibrium mixture of reactants. After charging, the cell can be used for supplying current when required, as the reaction sinks toward equilibrium again. Thus as the secondary cell can be used through a large number of cycles of discharging and charging. Such cells are also known as rechargeable cells, storage cells, or accumulators.

Eg. Lead-acid batteries, Nickel-cadmium cell, Lithium- ion battery

**1.6.2.1 Requirements of Primary Battery:**

* Compact, lightweight and must be fabricated from easily available raw materials.
* Economic and have benign environmental properties
* Should have a high energy density, longer shelf life
* Provide constant voltage and should have a long discharge period

**1.6.2.2 Requirements of Secondary Battery**

* Long shelf-life in both charged & discharged conditions
* Longer cycle life and design life
* High power to weight ratio
* Short time for a recharge.
* High voltage & high energy density

**1.6.2.3 Differences between Primary and Secondary batteries**

|  |  |
| --- | --- |
| Primary Batteries | Secondary Batteries |
| 1.Cell reaction is irreversible | Cell reaction is reversible |
| 2. They must be discarded after its active elements have been consumed | They may be recharged a number of times from an external d.c. source during its useful life |
| 3. Have a relatively short shelf life | Have a very long shelf life |
| 4. Function only as galvanic cells | Function as galvanic cells during discharge as & as electrolytic cells during the charging process. |
| 5. They cannot be used as energy storage devices | They can be used as energy storage devices (e.g. solar/ thermal energy converted to electrical energy) |
| 6. They cannot be recharged | They can be recharged. |
| e.g. Dry cell, Li-MnO2 battery | e.g. Lead acid battery, Ni-cd battery |

**1.6.3 Lead Storage Battery** (Lead Accumulator or Car Battery or The acid battery)

***Construction:*** The electrodes are lead grids to maximize its surface area. The anode grid is filled with finely divided spongy lead (Pb) and the cathode grid is packed with lead dioxide (PbO2). Both electrodes are submerged in a sulfuric acid solution (H2SO4) having a specific gravity of about 1.25 that acts as the electrolyte. Anode and cathode grids are separated by insulators like strips of wood, rubber or glass fiber. In car batteries, six cells are connected in series (anode to cathode) to produce a 12–volt battery. The battery is encased in a plastic container or hard vulcanized rubber vessel. The cell doesn’t need to have a separate anode and cathode compartments because the oxidizing and reducing agents are both solids (PbO2 & Pb) that are kept from coming in contact by the presence of insulating spacers between the grids. Both anode and cathode are immersed in a common electrolyte (i.e. cell without liquid junction). This is an example of a ‘wet cell’, because the electrolyte is an aqueous solution of sulphuric acid. The lead acid battery is very widely manufactured – 300 million units are made each year.

***Working:***Electrode reactions during discharging:

At the anode:

Pb(s) → Pb2+(aq) + 2e−

Pb2+(aq) + SO42−(aq) → PbSO4(s)

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Pb(s) + SO42−(aq) → PbSO4(aq) + 2e−

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At the cathode:

PbO2(s) + 4H+(aq) + 2e− → Pb2+(aq) + 2H2O(l)

Pb2+(aq) + SO42−(aq) → PbSO4(s)

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PbO2(s) + 4H+(aq) + SO42−(aq) + 2e− → 2 PbSO4(s) + 2H2O(l)

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Overall: Pb(s) + PbO2(s) +4H+(aq) + 2SO42−(aq) → 2PbSO4(s) + 2H2O(l)

***Explanation:*** At the anode, lead atoms lose two electrons (e-) and become positively charged lead ions (Pb2+). The lead ions combine with the sulfate ions (SO42-) in the sulfuric acid solution to produce lead sulfate (PbSO4). At the cathode, lead dioxide gains electrons, releasing oxygen, which attaches to hydrogen ions (H+) to produce water (H2O (l) and lead ions. The lead ions react with sulfate ions to produce lead sulfate. As this reaction progresses, the flow of electrons creates an electric current. Lead sulfate adheres on each electrode and water increases. The concentration of sulfuric acid decreases and the amount of lead and lead dioxide decrease. When the reactants are depleted, the battery stops producing electricity. The reaction can be reversed by recharging the battery & the PbSO4 formed during discharge remains adhered on each electrode and is available at the site during recharging. The nominal voltage of each cell is about 2.1 V. The lead storage battery is designed to operate reversibly, so that it can be used for the storage of electrical energy. They are called storage batteries because their essential function is to store electrical energy. It is used to store energy in chemical form.

***Reactions during Charging:***

Anode: PbSO4(s) + 2e- → Pb(s)+ SO42-(aq)

Cathode: PbSO4(s) + 2H2O(l) → PbO2(s) + SO42-(aq) + 4H +(aq) +2e-

Net reaction: 2PbSO4(s) + 2H2O(l) → Pb(s) + PbO2(s) +2H2SO4

Recharging is possible because PbSO4 formed during discharge adheres to the electrodes. By attaching an external power source to a battery ( >2 volts), a current runs through the poles in the opposite direction from normal discharge. This changes the lead sulfate and water back into the original reactants, lead dioxide and sulfuric acid, i.e. the electrodes return to their former composition and the sulfuric acid is regenerated. Charging, therefore, produces a gradual increase in the sulfuric acid concentration. Since the level of charge on a storage battery is related to sulfuric acid concentration, the specific gravity of the H2SO4 solution is a measure of the operational condition of a battery. A charged battery at room temperature with its electrolyte at normal concentration supplies a potential difference of 2.1 to 2.2 V. The complete reaction cycle of a lead acid storage battery is as follows.

Discharge

Charge

Pb(s) + PbO2 + 2 H2SO4(aq)

H2SO4(aq)

2 PbSO4(s) + 2 H2O(l)

In an automobile, the energy necessary for recharging the battery is provided by the generator driven by the engine. As the external source forces electrons from one electrode to another, the PbSO4 is converted to Pb at one electrode & to PbO2 at the other.

***Overcharging*:**

Electrolysis of water: The net reaction can be summarized by the equation.

2H2O (l) + electrical energy → 2H2(g) + O2(g)

No gases will be liberated on charging as long as lead ions are present in solution. If the electrolysis is permitted to proceed further, hydrogen gas is formed at the cathode and oxygen gas is evolved at the anode. The hydrogen ions are discharged at the cathode through the reaction

2H+(aq) + 2e-→ H2(g)

Sulphate ions are resistant to oxidation and are not discharged at the cathode. Water is oxidized at the anode in preference to SO42-

2H2O(l) →O2(g) + 4H+(aq) +4e-

Consequences: (i) Excessive charging may reduce the acid level and may damage the exposed electrode grids (ii) In extreme cases, there will be dangerous high-pressure build-up that can lead to a serious risk of explosion. In more normal circumstances, the older version of the battery needs to be ‘topped up’ from time to time.

Recent years have seen the introduction of “maintenance – free batteries” without a gas – release vent. Here the gassing is controlled by careful choice of the composition of the lead alloys used i.e. by using a Pb-Ca (0.1 % ) as the anode which inhibits the electrolysis of water.

Alternatively, some modern batteries contain a catalyst (e.g. a mixture of 98% ceria (cerium oxide) & 2% platinum) that combines the hydrogen and oxygen produced during discharge back into the water. Thus the battery retains its potency and requires no maintenance. Such batteries are sealed as there is no need to add water and this sealing prevents leakage of cell materials.

***Applications*:** The many battery designs available for a wide variety of uses can be classified into three main categories. (a) Automotive (b) Industrial & (c) Consumer batteries.

The automotive type is used in cars and trucks, to provide a short burst of power for starting the engine. It is incorporated as an essential accessory into the starting circuit of internal combustion engines for starting, lighting & ignition (SLI). Units normally have nominal voltages of 12 V for LMVS and 24 V for HGVS. It is still playing a major role in transportation, powering literally millions of ICES in automobiles. The industrial batteries are used for heavy–duty applications such as motive and standby power. This class of batteries is used to operate electric trucks, submarines and mine locomotives. They also provide power for the air conditioning and lighting systems. It is used in the stationary back–up power applications such as telecommunication systems, because, the telephone network will continue to operate even in the event of a mains power failure. Such batteries are kept in hospital operating theaters, railway signal centres and other places where a power failure might be disastrous and is used to supply electrical power during emergencies. The consumer batteries are used in a emergency lighting systems, security and alarm systems, public address systems, power tools, UPS in computers, and small engine starting including electronic vehicles.

***Advantages:***

* A lead storage battery is highly efficient. The voltage efficiency of the cell is defined as follows.
* Voltage efficiency = average voltage during discharge

average voltage during charge

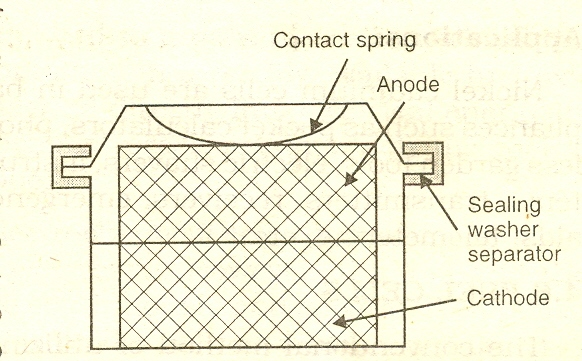
* The voltage efficiency of the lead – acid cell is about 80 %.
* The near reversibility is a consequence of the faster rate of the chemical reactions in the cell i.e. anode oxidizes easily and cathode reduces easily leading to an overall reaction with a high negative free energy change.
* A lead – acid battery provides a good service for several years. The number of recharges possible range from 300 to 1500, depending on the battery’s design and conditions. The sealed lead-acid batteries can withstand up to 2000 – recharging. Time required for recharging is relatively low i.e about 2-8 hours.
* The battery has low internal self – discharge.
* A typical car battery provides a voltage of 12 V. This is not a large voltage, but the battery can provide a large current. E.g. over 10 A, without being destroyed.

***Disadvantages:***

* If left unused in partially charged condition, it can be ruined in a short time by nucleation and the growth of relatively large PbSO4 crystals, which are not easily reduced or oxidized by the charging current. This disaster is known as ‘sulfation’.
* The lead acid battery has low energy storage to weight ratio i.e. its chief disadvantages is its great weight.(energy density ~ 35 wh / kg)
* The cell potential decreases with a decrease in concentration of sulfuric acid. During the discharge process sulfuric acid is consumed and water is produced. So the solution of sulfuric acid in the cell becomes less concentrated. The state of charge of the cell can be judged by the concentration of sulfuric acid in the liquid and this is usually done with a simple device to measure the density of the liquid. The density of a healthy, fully charged battery is ≥ 1.25 g/mL.
* The battery is not efficient at a lower temperature. For a battery to function properly, the electrolyte must be fully conducting. There will be an increase in the viscosity of the electrolyte due to a decrease in the temperature. This leads to a decrease in the cell potential.
* Overcharging may damage the exposed electrodes and may also lead to an explosion in extreme cases. Sulfuric acid is highly corrosive liquid. In the event of an explosion, the electrolyte is sprayed on to the individual who is working on the battery. Therefore, safety goggles must be worn when working with these batteries.
* Lead is toxic and hence environmental & health problems arise due to careless disposal by consumers.
* The corrosion of the lead grid at the lead dioxide electrode is one of the primary causes of lead acid battery failure.

**1.6.4 Nickel-Cadmium Cell**

***Construction*:** NiCad cell consists of a nickel wire gauze electrode grids. The anode grid consists of spongy cadmium metal and the cathode grid contains the nicked (III) compound NiO(OH). The electrolyte is a concentrated solution of KOH. It is the electrolyte of choice because of its compatibility with the various electrodes, good conductivity and low freezing point temperature (about – 30o C). Anode and cathode are separated by a very thin separator. The contents are encased as a sealed unit in a steel case.



**Figure 1.6.4** Schematic representation of NiCad cell

***Working:***

Discharging reactions

Anode: Cd(s) + 2OH-(aq) → Cd(OH)2(s) + 2e-

Cathode: 2NiO(OH)(s) + 2H2O + 2e- → 2Ni(OH)2(s) + 2OH-(aq)

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Cd(s) + 2NiO(OH)(s) + 2H2O → 2 Ni(OH)2(s) + Cd(OH)2(s)

Charging reactions:

Anode: Cd(OH)2(s) + 2e-→ Cd(s) + 2OH-(aq)

Cathode: 2 Ni(OH)2(s) + 2OH-(aq) → 2 NiO(OH)(s) + 2H2O+2e-

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Overall reaction: 2 Ni(OH)2(s) + Cd(OH)2(s) → 2 NiO(OH)(s) + Cd(s) +2H2O(l)

**Explanation:** At anode cadmium metal undergoes oxidation from 0 to +2, leaving behind two electrons for every atom oxidized, as the cell discharges. At cathode nickel is reduced from the +3 oxidation state (in nickel oxide hydroxide) to +2 (in nickel hydroxide). Note that OH- is not used up as the cell is discharged. Therefore, there is no voltage drop through most of the useful life of the battery as it discharges. The net reaction can take place until the active materials are exhausted. During charging process, the cadmium hydroxide is re-converted into cadmium and the nickelous hydroxide is reconverted to nickel oxide hydroxide. The overall chemical reaction of the Ni-Cd system may be represented as



Cd + 2 NiO(OH) + 2H2O Cd(OH)2 + 2Ni(OH)2

The cell must be recharged by applying the correct dc charging voltage.

***Applications:*** Nicad cells are available in standard sizes (AA, D, C, F etc.) for use in flash lights, photoflash units and portable electronic equipment such as radios, micro tape recorders, calculators, cordless phones, electronic shavers, drills & garden tools. It is also used in emergency lighting systems, alarm systems, personal audio equipment (walkman type cassette players), kitchen appliances and other battery powered small tools, toys & games.

***Advantages:***

* Ni-cad batteries can be recharged many times because the solid products of the electrode reactions adhere to the surface of the electrodes. Normally this battery can withstand up to 3000 – recharging (longer cycle life)
* They maintain nearly constant voltage level throughout their discharge. Note that there is no change in the electrolyte composition during the operation.
* It can be left unused for long periods of time at any state of charge without any appreciable damage (i.e. long shelf life).
* It can be encased as a sealed unit like the dry cell because gassing will not occur during nominal discharging or recharging.
* They possess a longer design life. It can be extended upto 30 years or more if maintained.
* They exhibit good performance ability at low temperatures.
* They can be used to produce large instantaneous currents as high as 1000-8000 A for one second.

***Disadvantages:***

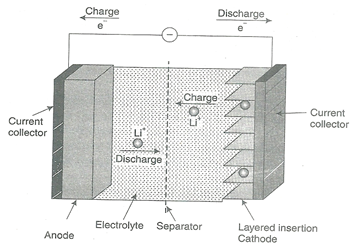
* It poses an environmental pollution hazard due to careless disposal by consumers and produces health problems (decreases range from asthma to cancer) due to higher toxicity of metallic cadmium than lead.
* Cadmium is a heavy metal and its use increases the weight of batteries, particularly in larger versions. The energy density is approximately 40 Wh/kg.
* Cost of cadmium metal and hence the cost of construction of NiCad batteries is high. The overall capital cost of these batteries is roughly higher than that of lead storage batteries.
* The KOH electrolyte used is a corrosive hazardous chemical. It is a poison and if ingested attacks the throat and stomach linings. Eye contact can result in severe burns and blindness. Protective clothing and face shields or goggles should be worn while performing maintenance work.

**1.6.5 Lithium ion cells**

Lithium metal cannot be used safely in secondary batteries. Hence, various lithium compounds have been made, which are used in rechargeable batteries, commonly known as Lithium –Ion Cells. In these type of batteries, a lithiated metal oxide such as LiCoO2, LiV2O5, LiMn2O4 etc is inserted into the cathode which consists of a layered graphite crystal. The electrolyte is normally LiPF6, but LiBF4 can also be used as LiPF6 is not corrosion resistant.

***Construction:***

The anode is a lithium-carbide intercalate (LixC6). The cathode is a transition metal oxide MO2 of variable oxidation state (MnO2, CoO2, NiO2) which can intercalate lithium usually cobalt dioxide, CoO2 is used. The electrolyte is usually inert polar dry ether or carbonate (diethyl carbonate or propylene carbonate), in which a conductivity salt such as LiPF6 or LiBF4 is dissolved.



**Figure 1.6.5** Schematic diagram of Rechargeable lithium ion battery

***Working:*** Graphite has a layered structure and its electrochemically reduced in an aprotic organic electrolyte containing lithium salts and lithium in interclated (or doped) between the layers of graphite to form Lithium-Graphite interclated compound (GIC). Li-GIC undergoes oxidation leaving an electron.

At anode:

* LixC6 xLi+(solv) + 6C(s) + xe-………………………….(1)

When a negative electrode is discharged, lithium is deinterclated (undoped) from lithiated graphite and lithium ions dissolve into the elctrolyte. The lithium content in the LiCoO2 electrode reversibly changes during charge and discharge as indicated in the following equation:

At cathode:

* CoO2(s) + xLi+(solv) + xe- LixCoO2(s)……………….(2)

Net cell reaction**:**

LixC6(s) + CoO2 Discharge LixCoO2(s) + 6C………………….(3)

Charge

***Explanation*s:** It is called as a lithium ion battery to emphasise that it contains no lithium metal. Both the electrodes are intercalation compounds. The electrode on the left serves as the anode when the cell discharges. It is a special intercalation compound consisting of a graphite host into which lithium ions have been electrochemically inserted between the carbon atom layers. The lithiated graphite is written as LixC6. During the discharge, the lithium ions are extracted by the half-reaction (1). The electrode that serves as cathode during discharge is normally cobalt dioxide. The reduction half reaction is cathode during discharge is normally cobalt dioxide. The reduction half reaction shown in eq.(2), where cobalt undergoes reduction from IV to III oxidation state. The overall reaction is shown in eq.(3). During discharge the Li+  ions spontaneously migrate from the lithium graphite anode to the CoO2 cathode enablingcurrent to flow through the external circuit. When charged, cobalt ions are oxidized and lithium ions migrate into the graphite, when discharging the battery delivers energy to the external load and when charging it recieves energy from a d.c. power source. The electrode that acts as an anode, during discharging becomes a cathode when its charging.

***Applications:***

* Lithium-ion batteries are most commonly used in applications where one or more of the advantages (size, weight or energy) outweigh the additional cost, such as mobile telephones and mobile computing devices.
* Lithium-ion-polymer batteries are used when the battery design matters in a particular application as different designs are possible (Cylindrical, jelly-roll design, flat rectangular).
* It is used in current-generation laptops, cellular phones, video-recorders.
* It is also used in portable CD players, televisions and implantable medical devices.

***Advantages:***

* Lithium-ion batteries were designed to overcome the safety problems associated with the highly reactive properties of Lithium metal.
* Long cycle life (400-1200 cycles).
* They are smaller, lighter and provide greater energy density than either nickel-cadmium or nickel-metal-hydride batteries
* They can be operated in a wide temperature range and can be recharged before they are fully discharged.
* Typically designed to be recharged in the device rather than in an external charger.
* The average voltage of a Li-ion battery is equivalent to three Ni-Cd cells.

***Disadvantages:***

* Poor charge retention.
* The self discharge rate is about 10% per month.
* It prices are high compared to other types of cells commonly used.

**1.7 Fuel cells**

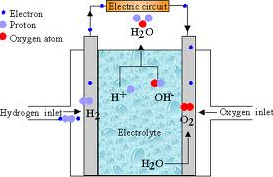
A fuel cell is a galvanic cell of a special type in which chemical energy contained in a fuel – oxidant system is converted directly into electrical energy in a continuous electrochemical process. It is an energy conversion device or electricity producer. The fuel cell has two electrodes and an electrolyte like a primary cell. The reactants (i.e. fuel + oxidant) are constantly supplied from outside and the products are removed at the same rate as they are formed.

Cell: Fuel/ electrode/electrolyte/electrode/oxidant.

Anode: Fuel + oxygen ----------->Oxidation products+ ne-

Cathode: Oxidant + ne- ---------->Reduction products

A fuel cell consists of fuel, electrodes, electrolyte, & oxidant. Fuel undergoes oxidation at the anode and oxidant gets reduced at the cathode. The cell can produce current as long as the reactants are supplied. Most fuel cells produce low voltages, commonly less than one volt, so a number of them are connected in series in “fuel batteries.”



**Figure 1.7** Fuel cell

Eg:- H2-O2 fuel cell, CH3OH-O2 fuel cell, Solid-oxide fuel cell, Molten carbonate fuel cell

**1.7.1 Advantages of fuel cells**

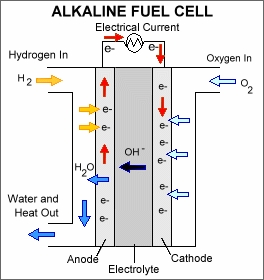
* High fuel to electricity conversion efficiency of 70-75 % while a thermal power plant converts 35-40% chemical energy of coal into electrical energy.
* Fuel cell products do not cause pollution problems such as noise pollution, chemical pollution and thermal pollution normally associated with conversional power plants.
* Fuel cell power plants can be located near the point of use electricity such as on an urban location, rather than at a remote place. So transmission and distribution lose (~30%) could be avoided.
* A fuel cell will produce a steady electric current as long as fresh reactants are available.

**1.7.2 Classification of fuel cells**

|  |  |  |
| --- | --- | --- |
| S. No. | Fuel cell type | Electrolyte used |
| 1 | Polymer electrolyte | Polymer membrane |
| 2 | Direct methanol | Polymer membrane |
| 3. | Alkaline | Potassium hydroxide |
| 4. | Phosphoric acid | Phosphoric acid |
| 5. | Molten carbonate | Lithium/potassium carbonate |
| 6. | Solid oxide | Yittria stabilized zirconia |

**1.7.3 Alkaline fuel cell (AFC)**

***Construction:*** Both electrodes are made up of porous carbon impregnated with finally- divided platinum. Potassium hydroxide is used as electrolyte is placed in the central compartment. The hydrogen gas is continuously supplied at the anode and pure oxygen gas is continuously supplied at the cathode form an external reservoir. The cell operates at about 80 oC and the normal voltage is 1.10 V. At the anode, hydrogen is oxidized to the H+ ions, which are neutralized by the OH- ions of the electrolyte, forming water and electrons are released. At the cathode, oxygen and water take electrons to form hydroxide ions. The overall reaction is equivalent to the combustion of hydrogen. The only product discharge by the cell is water vapor that escapes through the exhaust point. Note that the gases H2 and O2 diffuse into the electrode pores and so does the electrolyte solution.



**Figure 1.7.3** AFC

***Working:***

At Anode:

* H2(g) + 2OH-(aq) 2H2O(l) + 2e-

At Cathode:

* O2(g) + H2O(l) + 2e- 2OH-(aq)

Overall: H2+ O2 H2O(l)

***Advantages:*** Desirable attributes of the AFC include its excellent performance on hydrogen (H2) and oxygen (O2) compared to other candidate fuel cells due to its active O2 electrode kinetics and its flexibility to use a wide range of electro-catalysts.

***Disadvantages:***

* The sensitivity of the electrolyte to CO2 requires the use of highly pure oxidant and fuel.
* As a consequence, the use of a reformer would require a highly effective CO and CO2 removal system.
* If ambient air is used as the oxidant, the CO2 in the air must be removed. While this is technically not challenging, it has a significant impact on the size and cost of the system.

***Applications:*** AFC is widely used in US space programs to produce electrical energy and water onboard spacecraft.

**1.7.4 Proton exchange membrane fuel cell (PEMFC)**

Polymer electrolyte membrane fuel cells – also called proton exchange membrane fuel cells – deliver high power density and offer the advantages of low weight and volume, compared to other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst. They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. Polymer electrolyte membrane fuel cells operate at relatively low temperatures, around 80 oC (176 oF).

Low temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen’s electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to CO poisoning, making it necessary to employ an additional reaction to reduce CO in the fuel gas if the hydrogen is derived from an alcohol or hydrocarbon fuel. This also adds cost. Developers are currently exploring Pt/Ru catalysts that are more resistant to CO.

***Role of Proton conducting membranes:***

* The membrane function in two ways: It acts as the electrolyte which provides ionic communication between the anode and the cathode and also it serves as the separator for the two-reactant gases.
* Optimized proton and water transport properties of the membrane and proper water management are crucial for efficient fuel cell operation.
* Dehydration of the membrane reduces the proton conductivity and excess of water can lead to the flooding of the electrolyte. Both conditions result in poor performance.
* The absence of solution-phase electrolyte in PEF fuel cells, compared to alkaline and phosphoric acid fuel cells greatly reduces the complexity of the fuel and oxidant flow controls.
* Polymeric electrolyte is carbon dioxide tolerant.
* The most important breakthrough came with the development of perflourinated membrane by DuPont. From 1966, the membrane requirements were best met by nafion family of perfluorinated ionomer membranes. Lifetimes over 60,000 hrs have been achieved at 353 K. Their general formula is



***Construction:***

**Electrolyte:-**Ion exchange polymeric membranes. This is an excellent insulator, but an excellent conductor of H+ ions. The material used, consists of a fluorocarbon polymer backbone, similar to Teflon, to which sulphonic acid groups are fixed to the polymer and cannot leak out, but the protons of these groups are free to migrate through the membrane.

**Electrodes:-**Typical gas diffusion electrodes, made up of porous C impregnated with Pt catalyst. Noble metal treated carbon fiber paper/cloth which is directly bonded to the polymer membrane at an elevated temperature and pressure (The catalytic electrode/membrane configuration is referred to as membrane electrodes assemble, MEA).

**Fuel:-** Hydrogen

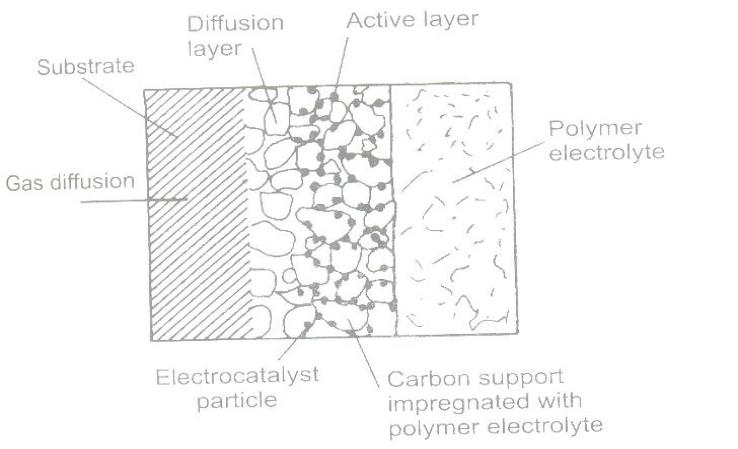
**Oxidant:**- Air

**Catalyst:-**Platinum

**Interconnect:-** Carbon or metal

**Operating temperature**:- 40 – 80 oC.

**Charge-carrier:-**H+

**-**

**Fig.1.7.5.1** schematic of a typical PEMFC electrode, which displays three layers

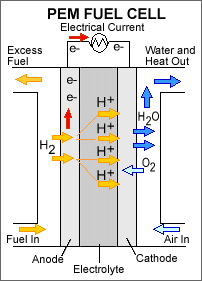
(i) A Teflonized substrate (typically, carbon cloth)

(ii) A diffusion layer, generally formed by carbon particles of about 0.1 μm size with Teflon.

(iii) An active layer, where Pt catalyst grains are supported on carbon particles (Pt loading is usually 0.4 mg/cm2or less) with or without Teflon.

***Cell reactions and Function of PEMFC:***

PEM fuel cells operate at around 80 oC and practical efficiency of 60 %. Power output is in the range of 5-200 KW. They are ideal for transportation and portable power. Additional advantages are their high response, small size and low cost. A polymer electrolyte membrane fuel cell is unusual in that its electrolyte consists of a layer of solid polymer which allows protons to be transmitted from one fact to the other. Porous carbon is used as the anode and cathode of the PEMFC, as shown in Fig. It basically requires H2 and O2 as its inputs, though the oxidant may also be ambient air, and these gases must be humidified. It operates at a low temperature because of the limitations imposed by the thermal properties of the membrane itself. The operating temperatures are around 90oC and a Pt catalyst is used.



**Fig.1.7.5.2** PEMFC

At anode:

* H2(g) 2H+(aq) + 2e-

At cathode

* O2(g) + 2H+(aq) + 2e- H2O(l)

Overall reaction: H2(g) + O(g) H2O(l)

***Applications:***

* PEM fuel cells are used primarily for transportation applications and some stationary applications.
* Due to their fast startup time, low sensitivity to orientation, and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses.

***Advantages:***

* The PEMFC has a solid electrolyte which provides excellent resistance to gas crossover.
* The PEMFCs low operating temperature allows rapid start-up and, with the absence of corrosive cell constituents, the use of the exotic materials required in other fuel cell types, both in stack construction.
* PEMFCs are capable of high current densities of over 2 kW/I and 2 W/cm2.

***Disadvantages:***

* The low and narrow operating temperature range makes thermal management difficult, especially at very high current densities, and makes it difficult to use the rejected heat for cogeneration.
* Optimized proton and water transport properties of the membrane and proper water management are crucial for efficient fuel cell operation. Dehydration of the membrane reduces the proton conductivity and excess water can lead to the flooding of the electrolyte. Both the conditions lead to poor performance.
* Perflourinated membranes have a high cost.
* PEMFCs are quite sensitive to poisoning by trace levels of contaminants including CO, sulfur species and ammonia.

**1.7.6 Differences between the fuel cell and galvanic cell:**

|  |  |
| --- | --- |
| **Fuel Cell** | **Galvanic Cell** |
| 1. They do not store chemical energy | They store chemical energy |
| 2. Reactants are fed from outside the cell continuously | The reactants from an integral part of its construction. |
| 3. Need expensive noble metal catalysts & an optimum to an operative for their efficient functioning. | These special conditions are not required |
| 4. Do not get discharged and no need of charging | Get-discharged when stored – up energy is exhausted. |
| 5. Such cells never become dead as long as fresh reactants are available | Limited life span in use |
| 6. Useful for long-term electricity generation. | Useful as portable power services. |
| 7.Reaction products must be continuously removed | No such problem |
| 8. No pollutants are generated (significant environmental benefits) | Pollutants are generated after their useful life |
| 9. Produce power from fuels | They cannot generate electricity from fuels |
| 10. Significantly higher power densities | Lower power density |