MODULE-2

Energy Storage and Conversion

Batteries- Definition, difference between battery and cell. Classification of batteries – primary & secondary batteries. Battery characteristics.

Secondary batteries - construction, working and industrial applications of Lead-acid battery and Nickel-metal hydride battery.

Modern batteries: Construction, working and industrial applications of Zinc-air battery, Nickel metal hydride battery and Li-ion battery.

Modern batteries: Construction, working and industrial applications of Li-ion battery.

Fuel Cells- Introduction, definition, construction, working and industrial applications of H_2-O_2 fuel cell & methanol-oxygen fuel cell. Differences between battery and fuel cells.

Green fuels:Power alcohol-Introduction, advantages and disadvantages. **Biodiesel**- Introduction, synthesis, advantages, and disadvantages.

E-waste management: Introduction, sources, types, effects of e-waste on environment and human health, methods of disposal, advantages of recycling, extraction of copper and gold from e-waste

10 hours

Battery Technology

The conversion of chemical energy into electrical energy is a function of cells or batteries. A cell designates a single unit consisting of anode, cathode and an electrolyte. The arrangement of two or more cells connected in series or parallel is called battery. Batteries are used in digital watches, calculators, electric bells, electric clocks, alarm systems, photoflash devices, emergency lighting, tape recorders, toys, telephone systems, digital camera, mobile phones, laptops, electric vehicles, space vehicles, military applications, etc,. They are also used in automobiles to start engines, UPS systems to run computers, etc.

Principal components of a battery:

The main components of a battery are:

1. Anode: It is a negative electrode where oxidation takes place. It gives out electrons to the external circuit during electrochemical reaction.

2. Cathode: It is a positive electrode where reduction takes place. It accepts electrons from the external circuit.

3. The electrolyte (Active mass in anode and cathode): It is an ionic conductor. The electrolyte is commonly a solution or slurry of acids or alkalis or salts having high ionic conductivity.

4. The separator: The material which electronically isolates anodes and cathodes in a battery to prevent internal short circuiting are referred to as separators. They are permeable to the electrolyte so as to maintain desired ionic conductivity. Thus, their main function is to transport ions from the anode compartment to the cathode compartment and vice-versa.

Classification of batteries:

Batteries are classified into two types

a) **Primary batteries:**

These are the batteries in which the cell reaction (chemical reaction) is irreversible. In primary batteries, as long as the active material is present, the electrical energy is obtained. These batteries cannot be recharged or reused because after some times the cell reaction stops and cell becomes dead.

Ex: Zn-MnO_2 battery, Li-MnO_2 battery, etc,

b) Secondary batteries:

These are the batteries in which the cell reaction (chemical reaction) is completely reversible. These are also known as rechargeable batteries or reversible batteries. They can be recharged to their original condition by passing the current through them in the direction opposite to that of discharge current. As a result a secondary battery can be used again and again for a long time by charging after discharge. Red-ox reaction gets reversed during recharging.

Ex: Lead – acid battery, Ni – Cd battery, etc.

Characteristics of a battery:

A battery is specifically designed, constructed and used based on the following characteristics.

Voltage or emf of the battery:

The voltage available form a battery depends upon the emf of the cell which constitutes the battery system. The emf of a battery is calculated using the Nernst equation

$$E_{cell} = E^o_{cell} - \frac{2.303\ RT}{nF} \log Q$$

$$E_{cell} = E^o_{cell} - \frac{2.303\ RT}{nF} \log [product]/[reactant]$$

Where $E^o_{cell} = E^o_{\ cathode} - E^o_{\ anode}$ and Q is the reaction quotient for the cell reaction at any stage of reaction, which is the ratio of molar concentrations of product molecules to that of reactant molecules.

Current:

Current is a measure of the rate at which the battery is discharging. A battery can deliver high current only when there is a rapid electron transfer reaction. Rapid electron transfer reaction is possible when the battery contains large quantities of active materials.

Capacity:

The capacity is the charge or amount of electricity that may be obtained from the battery during discharge and is measured in ampere hours (Ah). Capacity depends on the size of the battery and is determined by Faraday relation-

$$C = \frac{WnF}{M}$$

Where W is weight of the active material, M is the molar mass of the active material, C is the capacity in ampere hours and n is the no. of electrons involved in the reaction.

Cycle life:

It is applicable only to secondary batteries, which can be recharged. Primary batteries are not rechargeable (designed for single discharge) but secondary batteries are rechargeable and their cycle life must be high.

Cycle is a single charge and discharge of a secondary/rechargeable battery and the number of charging cycles to discharge cycles that are possible before failure occurs in the case of secondary batteries is termed as cycle life.

Energy density:

Energy density is a measure of how much energy can be extracted from a battery per unit weight or volume of a battery.

Power density:

It is a measure of how much power can be extracted from a battery per unit weight of a battery.

Energy efficiency:

It is also known as cell efficiency. It is applicable only for secondary batteries.

The energy efficiency of a storage battery (in percent) is defined as

% energy efficiency = energy released on discharge/ energy required for charge X 100.

It is given by a ratio of energy released on discharge to energy required for charge.

Higher the energy efficiency, better is the battery (batteries should have high energy efficiency). As the energy efficiency increases, then the quality of the battery also increases.

Shelf life or storage life:

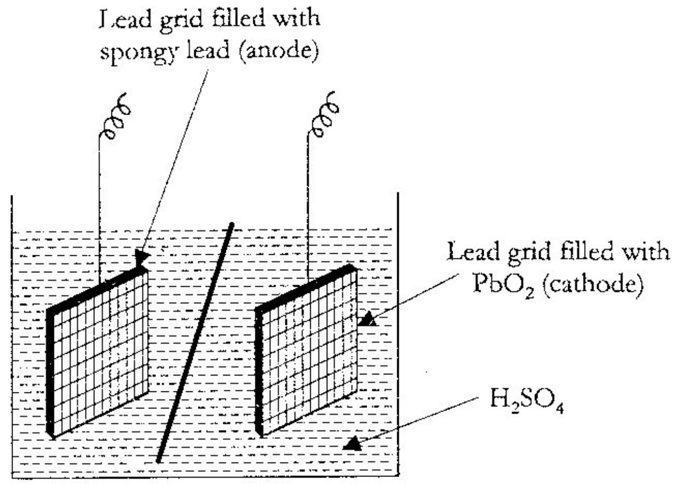
Shelf life is the maximum time for which a given battery can be stored without self discharge or corrosion or loss of performance. Good Shelf life is expected when there is no self discharge or

corrosion. Self discharge takes place when there is a reaction between the anode and cathode active materials. Self discharge and corrosion reduce the shelf life of a battery. A good battery is one which has high shelf life or storage life.

Construction, working and applications of some commercially important batteries:

Lead-acid battery:

Construction:



Lead-acid battery consists of two electrodes made of flat grids of lead. The anode grid is filled or packed with a paste of spongy lead metal (Pb) and other additives such as graphite powder (0.25 %), lignin sulphonate (0.2%), and barium sulphate (0.35%). The cathode grid is packed with a paste consisting of equal amount of lead dioxide (PbO_2) and lead. Several such pairs of anode & cathode grids are immersed or dipped alternatively in 5M or 37 % H_2SO_4, which acts as the electrolyte. The anode and cathode grids are separated by micro porous polyethylene separators.

Cell reactions during discharging of the battery:

At Anode, Lead electrode loses electrons, which flow through the external circuit. In this reaction oxidation of lead takes place.

$Pb \rightarrow Pb^{+2} + 2e^-$ ----------------- oxidation

$Pb^{+2} + SO_4^{-2} \rightarrow PbSO_4$

- -

$Pb + SO_4^{-2} \rightarrow PbSO_4 + 2e^-$

At Cathode, PbO_2 undergo reduction.

$PbO_2 + 4H^+ + 2e^- \rightarrow Pb^{+2} + 2H_2O$

$Pb^{+2} + SO_4^{-2} \rightarrow PbSO_4$

$$PbO_2 + 4H^+ + SO_4^{-2} + 2e^- \rightarrow PbSO_4 + 2H_2O$$

The net cell reaction is: $Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$

Recharging of the battery:

The condition of the battery can easily checked by measuring the density of the solution. When the density falls below 1.20 gm/cm^{3,} the battery needs charging. The battery is recharged by connecting it to an external source of direct current.

The net recharging reaction is,

$2PbSO_4+2H_2O$® $Pb + PbO_2+ 2H_2SO_4$

In general, the charging and discharging reaction is given by

Discharging

$Pb + PbO_2+ 2H_2SO_4$ $2PbSO_4 +2H_2O$ $\longrightarrow$

Charging

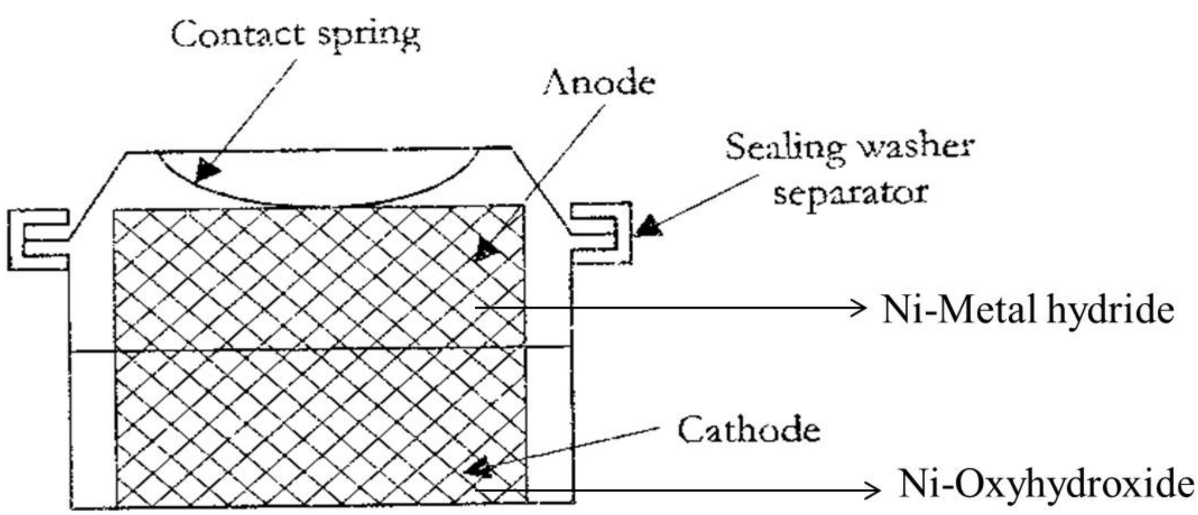
A lead-acid battery produces a potential of about 2.0 V/ cell. A typical 12V lead acid battery consists of six individual cells connected in series.

Applications:

Lead acid batteries are extensively used in automobiles to start the engine. It is also used in UPS systems to run the computers, used as a power source for laboratories, hospitals, emergency lighting, telephone exchangers, broadcasting stations, etc,.

Modern Batteries

Ni-MH battery:



It consists of rectangular Ni wire gauze electrode grids. The anode grid is coated with metal-hydride as active material. The cathode grid is coated with Ni-oxy hydroxide as active material. The anode and cathode grids are PP porous separator containing 21% KOH, which acts as electrolyte.

Cell reactions during discharging of battery are:

At anode:

$$MH + OH^- \longrightarrow M + H_2O + e^-$$

At cathode:

$$NiOOH + H_2O + e \longrightarrow Ni\,(OH)_2 + OH^-$$

The net cell reaction is

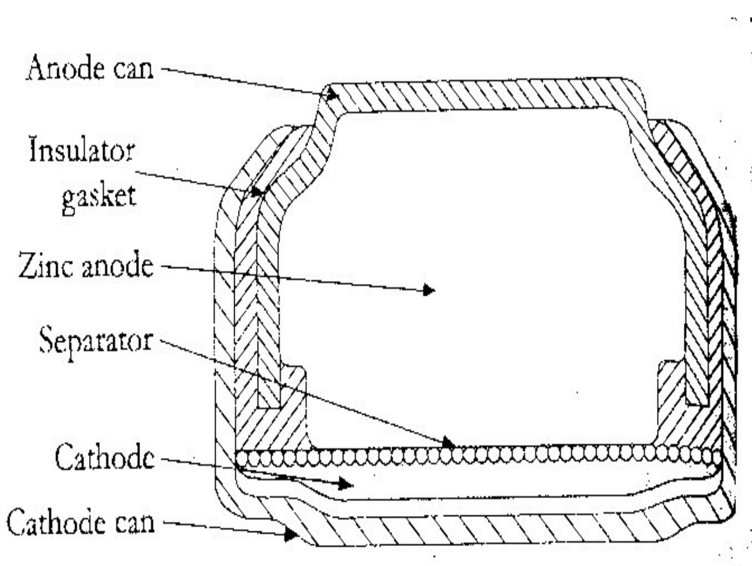
$$MH + NiOOH \longrightarrow M + Ni\,(OH)_2$$

This battery produces a potential of 1.25 v to 1.35v/cell

Applications:

It is used in digital camera, potable music player, cordless phones, cordless mouse, cordless key boards, laptops, electric vehicles, etc.

Zinc-air battery:



It is a secondary battery or rechargeable battery. Zinc- air battery belongs to the class of metal-air batteries, which use oxygen directly from the atmosphere to produce electrochemical energy. Oxygen diffuses into the cell and is used as the cathode reactant.

The Zn- air battery consists of an anode can and cathode cup. The loose, granulated powdered zinc is mixed with aqueous alkaline electrolyte (30 % KOH or NaOH) and a gelling agent (to immobilize the composite and ensure adequate contact with zinc granules). This mixture is filled completely into the anode can and is kept inverted over cathode cup. Pores carbon mixed with pallets of MnO_2 is taken at the bottom of cathode cup and is covered with nickel wire gauze mesh, which is coated or laminated with gas permeable Teflon layer. The two containers (anode cover and cathode cup) are separated by plastic gasket insulator. The two electrodes are separated by a porous separating membrane. The separating membrane is placed directly over the air access holes to uniform air distribution across the air electrode. Teflon layer allows oxygen, diffuse into and out of the cell and also provides resistance to leakage. The separator acts as an ionic conductor between the electrodes and as an insulator to prevent internal short circuiting. Holes in the battery allow the oxygen from the air to enter the cathode and be reduced on the carbon surface. At the same time, the Zn in the anode is oxidized.

During the cell reaction, pure air is admitted into the battery through the cavities of cathode, the oxygen of air diffuses through Teflon layer and adsorbed on the surface of MnO_2 and acts as cathode reactant. When air is passed through the cell, Zn is oxidized to ZnO at anode, during discharge. The oxygen of the air reacts with water at the cathode.

- **Electrode reactions are:**

At anode: $Zn®Zn^{+2}+2e^-$

$Zn^{+2}+2OH^-®\ ZnO+H_2O$

$Zn + 2\ OH^-®\ ZnO+H_2O +2e^-$

At cathode: $½\ O_2 +H_2O+2e^-®\ 2OH^-$

Net cell reaction $Zn + ½\ O_2®ZnO$

- This cell produces a potential of 1.4 V.
- During charging the above cell reaction is reversed.

Uses

- ✓ Used in hearing aids. It is used as a power source for hearing aids.
- ✓ In voice transmitters
- ✓ Used in military radio receivers
- ✓ In railway signals
- ✓ In remote communications,

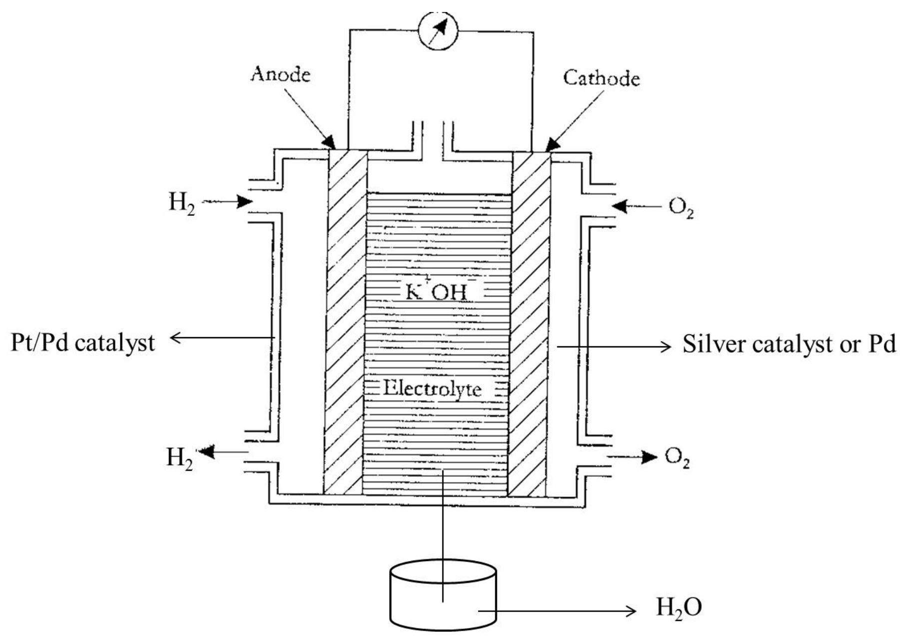
FUEL CELLS

Fuel cells are the galvanic cells in which the chemical energy of fuel is directly converted into electrical energy.

or

Fuel cell can be defined as galvanic cell in which the electrical energy is directly derived by the combustion of fuels supplied continuously.

H_2 - O_2 fuel cell



In this H_2 - O_2 fuel cell, hydrogen gas is used as a fuel and oxygen gas is used as oxidant. The

H_2 - O_2 fuel cell consists of two electrodes made of porous carbon or graphite. The anode is coated with finely divided platinum or palladium catalyst. The cathode is coated with platinum or silver catalyst. These two electrodes are placed in aqueous solution of KOH (30 %), which acts as electrolyte.

Cell reactions

At anode, hydrogen gas diffuse through the anode, it is absorbed on the electrode surface and reacts with hydroxyl ions to form water

$$2H_2\,(g) + 4\,OH^-\,(aq) \longrightarrow 4H_2O\,(l) + 4\,e^-$$

<u>At cathode,</u> O_2 diffuses through the cathode (electrode) and reacts with water molecules to form OH^- ions (reduction of oxygen takes place to OH^- ions).

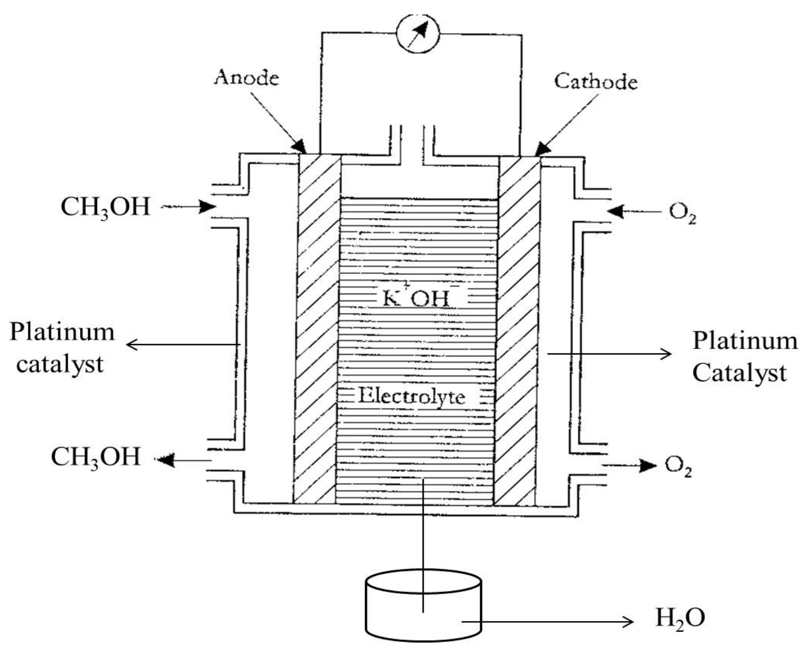
$$O_2\,(g) + 2H_2O\,(l) + 4e^- \longrightarrow 4\,OH^-$$

Net cell reaction: $$H_2\,(g) + O_2\,(g) \longrightarrow 2H_2O\,(l)$$

The net cell reaction is nothing but the combustion of H_2 and O_2. The water formed as the product, which dilutes the KOH. As a result, the cell becomes inactive. Therefore, the electrolyte is always kept hot so that water evaporates as fast as it is formed. A wick placed inside the electrolyte is also helps in removing and maintaining water balance. The cell produces an emf of 1.23V.

<u>Uses:</u> It is used as electric power source for space vehicles, military and mobile power system.

<u>Methanol- O_2 fuel cell:</u>



In this Methanol- O_2 fuel cell, hydrogen gas is used as a fuel and oxygen gas is used as oxidant. The Methanol- O_2 fuel cell consists of two electrodes made of porous Ni. The anode is coated with finely divided platinum or palladium catalyst. The cathode is coated with platinum or silver catalyst. These two electrodes are placed in aqueous solution of KOH (30 %), which acts as electrolyte.

<u>Cell reactions</u>

At anode, hydrogen gas diffuse through the anode, it is absorbed on the electrode surface and reacts with hydroxyl ions to form water.

$$CH_3OH + 6\ OH^- \longrightarrow CO_2 + 5H_2O + 6\ e^-$$

At cathode, O_2 diffuses through the cathode (electrode) and reacts with water molecules to form OH^- ions (reduction of oxygen takes place to OH^- ions).

$$3/2\ O_2 + 3H_2O + 6\ e^- \longrightarrow 6\ OH^-$$

Net cell reaction $$CH_3OH + 3/2\ O_2\,(g) \longrightarrow CO_2 + 2H_2O$$

The cell produces an emf of 1.23V.

Uses: It is used as electric power source for space vehicles, military and mobile power system

Differences between battery and fuel cell

Sl. No.	Battery	Fuel cell
1.	It is an effective energy storage system i.e. chemical energy is stored in the battery	It is an effective energy conversion system i.e. the energy is not stored in fuel cell.
2.	The reactants are not freely available and hence the production cost is more.	Fuels and oxidants are freely available, hence they are cheaper.
3.	It needs charging again and again.	No need of charging.
4.	The byproducts may be harmful and cause pollution.	Byproducts are eco-friendly and not cause any pollution.
5.	Efficiency of the battery is low	Efficiency of the fuel cell is high
6.	Reactants are used during the construction of battery	Reactants are introduced from outside the cell
7.	Battery operates until the reactants stored in it are completely used up	Fuel cell operates as long as the reactants are supplied to the electrodes from outside
8.	Ex: lead acid battery, Zn- air battery,	Ex: Hydrogen- oxygen fuel cell. Methane- Oxygen fuel cell, methanol- oxygen fuel cell, etc.

	Ni-Cd battery, etc.	

TEXT BOOKS

1. Engineering Chemistry by M.M.Uppal, Khanna Publishers (2001 edition).
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2. Industrial Chemistry by B. K. Sharma, GOEL Publishing House (2014 edition).
3. Industrial Electrochemistry, Second Edition by Derek Pletcher & Frank C. Walsh publisher: Chapman & Hall, USA (1993 edition).