

Electrochemical Technology in Pollution Control
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Lecture – 34
Batteries and fuel cells 3

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The nickel- cadmium cell is essentially similar to the nickel-iron cell excepting that cadmium is used instead of iron. The overall cell reaction for the passage of two faradays may be represented simplistically as follows:



Hello students, greetings to you. We will continue our discussion on the Batteries as well as a little bit about the fuel cells today. Yesterday I had talked to you about nickel cadmium cell that is essentially similar to nickel iron cell and I had shown you this slide. And now, I want to compare some of the alkaline rechargeable battery systems and their typical applications.

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Battery systems	Battery types	Battery applications	Salient features, advantages, limitations and remarks
Nickel - cadmium	A. Prismatic cells with pocket electrodes	Stationary/remote power requirements, load leveling	Easy to produce. Relatively low efficiency low energy per volume and weight. Open circuit voltage cell capacity 1.3 volts. Energy density (Wh/L) is 1.36. Specific energy is 1.21 Wh/L. Toxicity due to cd.
	B. Vented prismatic cells having sintered electrodes	Air craft batteries portable	High electrode efficiency, high cycle life, high rate capability, open circuit voltage cell capacity is 1.315 Ah. Energy density is 2.72 Wh/L. specific energy is 2.31 Wh/Kg. Toxicity of Cd
	C. Button cells having pressed powder electrodes	Low power applications	Small size. Amenable for mass production. Relatively low current capability. Toxicity due to cd.
	D. Sealed cylindrical cells with Jelly roll electrodes and prismatic cells with stacked electrodes	Portable high power and high energy applications	Relatively low electrode efficiency cadmium toxicity.

Actually, whenever we want to tell something about the batteries etcetera if we do not talk about the applications and salient features, it will be some sort of an anti-climax because, quite often we have to choose between various kinds of batteries. So, look at Nickel cadmium battery, it is a Prismatic cells with pocket electrodes etcetera. And battery applications include remote power load levelling stationary.

And then the salient feature among the salient features, you will see that the toxicity is one part in which I want you to concentrate and the other one is the limitations. So, in nickel cadmium batteries, you can see that the energy relatively low efficiency per volume and weight that is not very highly desirable.

So, open circuit voltage cell capacity should be about 1.3 volts, but toxicity due to cadmium is always there; that means, once the useful life is over, we are faced to the burden of cadmium

ditto with other types of cells. Here in prismatic cells pocket electrodes, sintered electrodes and powder; these are all different kinds of electrodes of different sizes etcetera.

For example, this prismatic cells having sintered electrodes are used more mainly in aircraft batteries and again toxicity of cadmium should be common. Then, button cells are there, nickel cadmium, low power applications, but toxicity we just really do not know how to recover very low quantities of cadmium even though we know that they are dangerous in the environment.

Similarly, sealed cylindrical cells are there with jellyroll electrodes, these are useful for very high power, but portable energy. So, relatively low electrode efficiency is one of the common result that happens whenever we draw high power current. So, look at nickel hydrogen battery. Again a similar problem, pressure vessels, thin electrode stacks are required and high-profile applications in space missions.

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Battery systems	Battery types	Battery applications	Salient features, advantages, limitations and remarks
Nickel - Hydrogen	Pressure vessel, thin electrode stacks	High profile applications in space mission ; As power systems for civil and military satellite applications.	High cycle life. High electrode efficiency. Easily chargeable. Resistant against possible abuse. Expensive. Difficult to manufacture, poor energy density and poor charge resistance. Open circuit voltage 1.3 V. Energy density 60 Wh/L. specific energy 50 Wh/kg.
Nickel - metal hydride	Sealed cylindrical, Jelly roll electrodes	Portable high power and high energy applications	High energy density, high cycle life, high negative electrode efficiency, expensive metals are used and hence costly, poor charges retention as compared to Ni-Cd cells ; cell capacity 1.3 V ; Energy density is 184 Wh/L specific energy is 55 Wh/L

Now, usually they do not do a use anything else apart from nickel hydrogen in space applications. So, as power systems for military, satellite applications etcetera only nickel hydrogen are useful. Again, the energy other things are essentially same 1.3 volts 60 watt hours energy density etcetera. Then, there is this nickel metal hydride is something special only that has come to the fore only since last 20 years and these metal hydrides are portable high power high energy applications.

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Battery systems	Battery types	Battery applications	Salient features, advantages, limitations and remarks
Silver- Zinc	Prismatic cells with flat plate electrodes	Military applications in aerospace, submarine and communications	High rate and energy density. Poor cycle life. Expensive because of use of silver ; cell capacity 1.6 V ; Energy density is 190 Wh/L ; specific energy is 90 Wh/L
Mn O ₂ - Zinc	Sealed cylindrical cells with concentric cylinder electrodes	Portable, low to moderate power application	Relatively cheap. Absence of Pb and Cd and hence environmentally safe relatively, alternate for primary alkaline batteries. Very poor cycle life. Rapid fall of capacity. Possible mercury contamination in some design. Cell capacity 1.5 V ; Energy density is 125 or 240 Wh/L for 10 to 1 cycle as the case may be ; specific energy is 90 Wh/L

So, apart from that there is not much to tell I want you to study all these applications with respect to their utility. Then comes Silver Zinc, Prismatic cells with the flat plate electrodes used in Military applications and marine communications. They are expensive because of the use of silver you see silver is an electrode that is not only toxic, but it is costly also. So, but

the current capacity wise and all it is very good 1.6 volts and 190 volts watt hours and then specific energy is approximately 90 watt hours per kg etcetera.

And MnO₂ Zinc electrode, Sealed cylindrical cells applications Portable low moderate power applications. Suppose you want to monitor you know SPM SO₂ etcetera in the environment were in the field then you should go for such electrodes batteries. They are relatively cheap and absence of lead and cadmium etcetera makes it environment friendly and they are alternates for primary alkaline batteries energy density is also quite attractive.

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Battery system	Nominal voltage	Remarks
Li - Mn oxide	3.0 V	Room temperature operation, positive electrode material is air-sensitive, problems due to plating of lithium
Li-V6O13	2.5 V	Solid polymeric electrolyte cross linked using radiation polymerisation, lithium plating problems
Li Ti - S ₂	2.3 V	Room temperature operation, air-sensitive positive electrode material, problem due to lithium plating
Al - Air	1.6 V	Circulating electrolyte, low efficiency negative electrodes, replaceable negative electrode
Li- Al - FeS	1.33 V	Fused salt electrolyte, problem due to corrosion
Ni Zn	1.65 V	High rate capability, low cycle life
Zn - Br	1.85 V	Circulating liquid phase contains bromine complex and the related container problem
Sodium - Nickel Chloride(or iron Chloride)	2.5 (or 2.3) V	Solid positive electrode, molten sodium is used as negative electrode, high temperature molten salt as catholyte and solid β - Al ₂ O ₃ separator
Sodium - Sulfur	2.1 V	β - Al ₂ O ₃ separator, high temperature liquid electrodes and containment problems.

I will not go into details of this, but these slides we have prepared for you to study and compare ok. Rechargeable battery systems under development I want to give you couple of remarks Lithium Manganese Oxide is 3 volts. Look at the research emphasis in getting higher

voltage for the same of electrodes and then remarks of course, I have put starting from the applications.

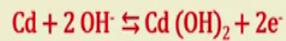
So, room temperature operation means very comfortable. positive electrode material is air sensitive; so, problems due to plating of lithium because the high if you want high voltage lithium should be very minimum. So, plating of lithium is required, then lithium this is another trademark battery available in the market commercially 2.5 volts lithium titanium S2 is 2.3 volts. We are having nothing better than that, comparable would be Sodium Nickel Chloride this would be approximately 2.5 to 2.3 volts, but very good.

But the they had they need high temperature molten salt as catholyte and solid BaAl_2O_3 separator; beta alumina that is Al_2O_3 . Here the problem is they would be useful only for specific applications rather than as a routine battery this thing. Similarly, Sodium sulfur 2.1 volts, beta alumina separator high temperature liquid electrodes difficult to handle but useful anyway.

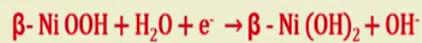
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The chemistry involved in all the above three types of nickel - cadmium batteries is same.

The cadmium electrode is discharged and charged in the overall reaction as follows



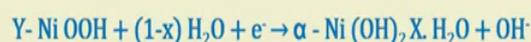
The normal reaction at nickel electrode is



So, the chemistry involved in all the above three types of nickel cadmium batteries is essentially same. We have already written the equations basically, it is conversion of cadmium to cadmium hydroxide with the release of 2 electrons and normal reaction would be beta nickel, oxide hydroxy peroxyacid, water plus electron that goes to beta nickel hydroxide and OH minus.

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However this reaction is complicated because of the existence of two additional phases that undergo electrochemical transformation under various conditions into the original phases.



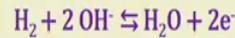
The γ -NiOOH phase appears in the system because of possible overcharging of the β -NiOOH electrode.

So, however, this reaction is basically complicated. You can imagine you see this is a proxy compound and here it is the only hydroxide and all the reaction that is happening is only due to this electron that is fantastic. So, this reaction is definitely complicated because of the existence of two additional phases that undergo electrochemical transformation and their various conditions.

And this is the type of real solid state reaction we write that is, Y moles of NiOOH and 1 minus X of H₂O plus e⁻ goes to alpha nickel hydroxide with X and that is X means variable water variable quantity of water plus O H minus. So, the gamma nickel proxy hydroxide phase appears in the system because of the possible overcharging of the beta NiOOH electrode.

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3. Nickel hydrogen batteries



The pressure vessel made of Inconel or stainless steel can withstand upto 200 bar.

4. Manganese dioxide - zinc battery

5. Silver - zinc Alkaline Battery

6. Rechargeable Lithium - ion Batteries

7. Rechargeable Lithium batteries

8. High temperature batteries

Now, let us talk a little bit about Nickel hydrogen batteries that makes it; its very simple H_2 plus 2OH^- goes to H_2O and pressure vessels made of Inconel or stainless steel they can withstand up to 200 bars. What does it mean? This 200 bars essentially are used such conditions prevail in submarines. So, that is why we need a an alloy like Inconel and other batteries are there Manganese dioxide zinc batteries, Silver zinc Alkaline battery.

There are various of batteries are available. And they would be having specific applications. We will not go into details of this except to say that there are lot of reserve batteries there has been a requirement of cells with special characteristics for the use in proximity fuses, artillery, mines, balloons, guided missiles, radar, bazookas, night viewing equipment and therefore, several times walkie talkies and several types of materials require these kind of batteries. And

they must have capability of high voltage as well as long inactive shelf life. This is very important; we want the batteries to have long shelf life even if they are not used.

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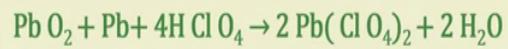
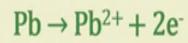
Reserve batteries

The recent years, there has been a requirement of cells with special characteristics for the use in proximity fuses, artillery, mines, pilot balloons, guided missiles, radars, bazookas, night-viewing equipment, sub-marine torpedo propulsion, walkie-talkies and special electronic equipment. Such batteries must withstand vibration, shock, extreme variation in temperatures and also must have capability of high voltage, long inactive shelf life, rapid activation to the ready state as and when required and must be available in different sizes and shapes.

So, the moment we use, it should come into life. So, rapid activation is one of the requirements for a good battery. So, here I can say a little bit about Perchloric acid and Fluoboric acid cells that is essentially lead perchloric acid, fluoboric acid and lead oxide reactions are similar. Lead goes to lead ion releasing 2 electrons and perchloric acid reaction produces lead perchlorate and this is another reaction $Pb + O_2 \rightarrow PbO_2$.

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1. Perchloric Acid and Fluoboric Acid Cells



2. Silver Chloride Cell

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3. The Gordon - Magnesium Battery

This cell consists of magnesium as the negative electrode and an oxygen (from air) depolarizer as the positive electrode. Tap water is used as the electrolyte. the cell may be represented as follows



So, similarly we can talk about that is the Silver Chloride Cell that is also very good and Gordon magnesium battery. This is one of the important batteries we containing magnesium as the negative electrode and oxygen depolarizer has the positive electrode. Here the most beautiful thing is tap water is used as the electrolyte.

So, we can simply write a cell reaction like magnesium as 1 electrode, Water as the electrolyte or KBr we can add KBr means Potassium Bromide in Aqueous solution. So, water also is one of the electrolyte plus oxygen gas from the air then carbon as the another electrode. So, Silver Peroxide Zinc Alkaline Cell was designed during the Second World War to meet the requirement of high rate primary cell; however, during investigations we find that the cell was best suited for one shot purpose.

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4. Silver Peroxide -Zinc Alkaline Cell

This cell was designed during the Second World War to meet the requirement for high rate primary cell. However, during investigations, it was found that the cell was best suited for "one shot" purposes because of its shorter shelf life, arising out of the high solubility of Silver oxide in NaOH or KOH used as electrolyte. Thus, this cell because a reserve- type cell which can activated at the time of use. the cell may be represented as follows



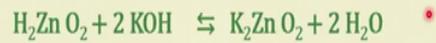
Because of the shorter shelf life arising out of the high solubility of Silver Oxide in Na OH or KOH that is why these cells are almost obsolete now. Nobody uses this kind of cells in silver silver oxide KOH because they are all one-time cells. So, you ready to forego the reuse, then you can use this type of cells.

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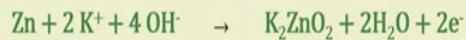
The reactions at the silver oxide electrode (positive electrode) occurs in two reduction steps :



The reactions at the zinc electrode (negative electrode) are as follows



Then, the overall reaction at the zinc electrode is as follows:



Then the reactions at the silver oxide electrode occurs in two reduction steps; first is silver oxide goes to Ag₂O this is Ag₂O and then Ag₂O goes to Ag that is silver. So, at the zinc electrode, again we have the final product would be K₂ZnO₂ plus 2H₂O. So, the overall reaction at the zinc electrode you can write that is zinc plus 2 K plus plus 4 OH minus goes to K₂ZnO₂ plus 2H₂O plus 2e minus.

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Fuel cells

A. Introduction

A fuel cell is an electrochemical cell which can convert the chemical energy contained in a readily available fuel-oxidant system into electrical energy by an electro chemical process, in which the fuel is oxidised at the anode.

Fuel cells work at high efficiency and the resulting emission levels are far the permissible limits. Fuel cell systems are modular and hence can be built in a wide range of power requirements from a few hundred watts upto multi kilo watt and even megawatt sizes.

So, that completes our discussion on various kinds of cells that is battery cells. We had discussed about nickel cadmium, air, water, silver oxide and then the lithium batteries and then nickel air all those things.

Now I will introduce you quickly to another part of the electrochemical technology that is known as fuel cell, we will not go into details, but we will just have a glimpse of what is a fuel cell. This is for the sake of gravity that we should not leave out anything related to electrochemical technology that is used in the pollution monitoring.

So, what is a fuel cell? A fuel cell is an electrochemical cell that can convert chemical energy contained in a readily available fuel oxidant system into electrical energy. So, they work at high efficiency resulting in emission levels that are for the far more than the permissible limits.

So, they are modular in nature, they can be built in a wide range of power requirements from a few 100 watts up to multi kilo watt and even megawatt sizes.

See, here the beauty of fuel cell comes into play. You know the fuel cells are required not in not only on the earth but even in space applications where a rocket or a satellite has to keep on working for years together based on its own chemical system. Basically, what is a fuel cell? It converts electrochemical chemical energy into a reusable electrical system. So, the chemical must be released slowly.

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B. Theoretical principle

The conventional process of utilizing the chemical energy of a fuel may be depicted as follows

Chemical energy → heat → mechanical → electrical energy

The basic arrangement in a fuel cell can be represented as follows

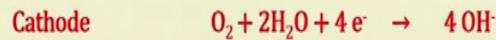
Fuel | Electrode || Electrode | oxidant

So, that electrical energy keeps on being supplied to the system. So, it works for longer time. So, what are the basic theoretical principles? Very simple, we have a chemical energy that goes to heat, then it is mechanical energy converted and then into electrical energy. So, we

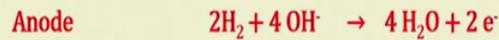
need a fuel, we need an electrode and we need another electrode and we need an oxidant. So, both oxidant and fuel can combine to give you electrical energy.

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In case of hydrogen - oxygen fuel cell having porous electrodes and potassium hydroxide as electrolyte, the following reaction take place.



The cathode reaction given above is the sum of the above intermediate reaction occurring at the cathode



So, there are several types of fuel cells with hydrogen oxygen fuel cell having porous electrodes and potassium hydroxide as the electrolyte simple reactions O_2 plus $2\text{H}_2\text{O}$ plus 4e^- was to 4OH^- minus. And the cathode reaction above is the sum of the intermediate reactions occurring at the cathode that is 2H_2 plus 4OH^- minus plus $4\text{H}_2\text{O}$ plus goes to 4 water and 2 electrons. These two electrons are again used up here and the overall reaction would be 2H_2 plus O_2 goes to $2\text{H}_2\text{O}$.

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1. The fuel cell electrode design should provide for promoting a high rate of electrode processes by creating a stable interface between the three phases, viz, the solid electrode, the liquid electrolyte and the gases fuel. Some of the electrodes used are Platinum, Porus PVC, Teflon coated with silver, Nickel Boride, raney nickel, etc.

So, the products of the fuel cells are always water and maybe a little bit of carbon dioxide depends. So, the fuel cell electrode design normally provides for high rate of electrode processes by creating stable interface between the three phases that is solid, liquid and gases.

So, all these three must be used up and thrown out; used up and thrown out; used up and thrown out some of the electrodes used are Platinum, Porous PVC, and Teflon coated with silver, Nickel Boride, raney nickel and many of the simple metallic systems which we are quite familiar in our day to day industrial life.

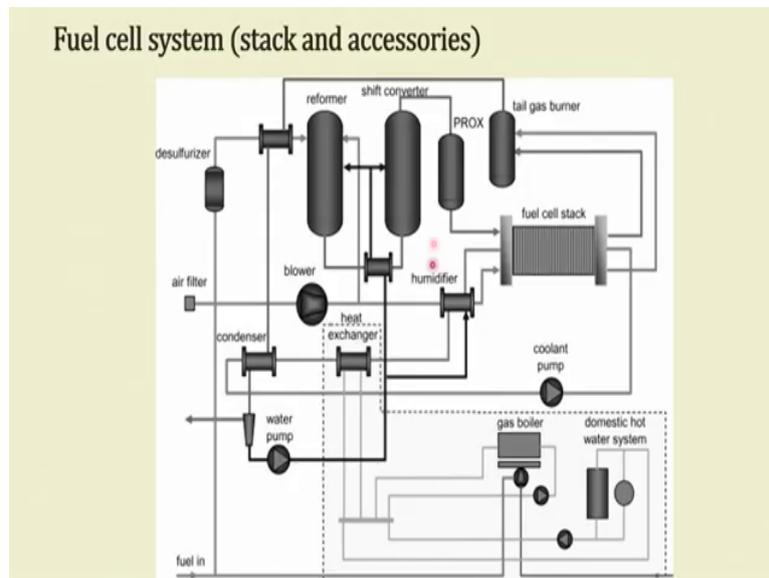
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2. The oxidants used include oxygen, air hydrogen peroxide and nitric acid, oxygen is used as oxidant in many fuel cells employing aqueous electrolytes because it is cheap and readily available.

3. The reactions proceed at a faster rate at increased temperature and also in pressure of suitable catalyst.

So, what are the oxidants? The oxidants include oxygen, air hydrogen peroxide nitric acid any of the oxidant will do the job and oxygen is used as the oxidant in many fuel cells because it can be attached in a cylinder. And then the cylinder can be supply opened at a with a needle wall to supply very small quantity of silver. So, the oxygen continuously to the system so, that the fuel cell keeps on working.

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So, the reactions proceed at a faster rate at increased temperature and also in pressure increased pressure also with suitable catalyst. So, here is a Fuel cell system stack, here is the fuel cell stack; all other things are normally systems required. This is a system not nothing to do with the fuel cell. This is some other system, I am not going into details of what is this.

It is a catalytic converter reactor petrol in a petrochemical complex, but these power supply is from fuel cell stack here. So, this kind of applications one can use especially in refineries and satellites and other places. So, from the practical point of view fuel systems are like this alkaline fuel cells are there and then Molten Carbonate Fuel cells, Phosphoric acid fuel cells, Solid oxide and Proton exchange membrane fuel cells.

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From the particle point of view, fuel systems are distinguished on the basis of the type of electrolyte used

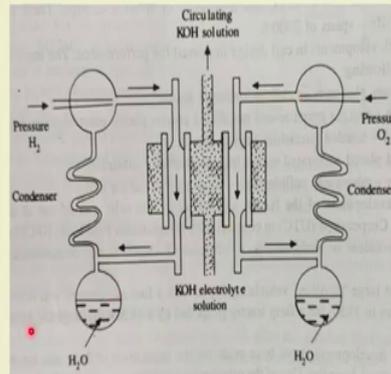
1. Alkaline fuel cells (AFC)
2. Molten Carbonate Fuel Cells (MCFC)
3. Phosphoric acid fuel cells (PAFC)
4. Solid oxide fuel cell (SOFC)
5. Proton exchange membrane fuel cells (PEMFC)

So, alkaline fuel cells equipped with a dual loop water removal system. Here we can see that the electrolyte is KOH again and then the pressure hydrogen comes here hydrogen fuel cell. So, there is a reaction with the KOH producing water. Here also it a similarly kind of reaction, this is a sort of mirror image left and right, but both of them are working in tandem.

So, this is the alkaline fuel cell called as dual loop water system also. And then Molten Carbonate cells, we can simply write the reaction with very simple components that is hydrogen and carbonate goes to H_2O plus CO_2 that is very simple known reaction like soda ok.

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1. Alkaline fuel cells (AFC)



Alkaline Fuel Cell equipped with dual-loop water removal system with circulating jets

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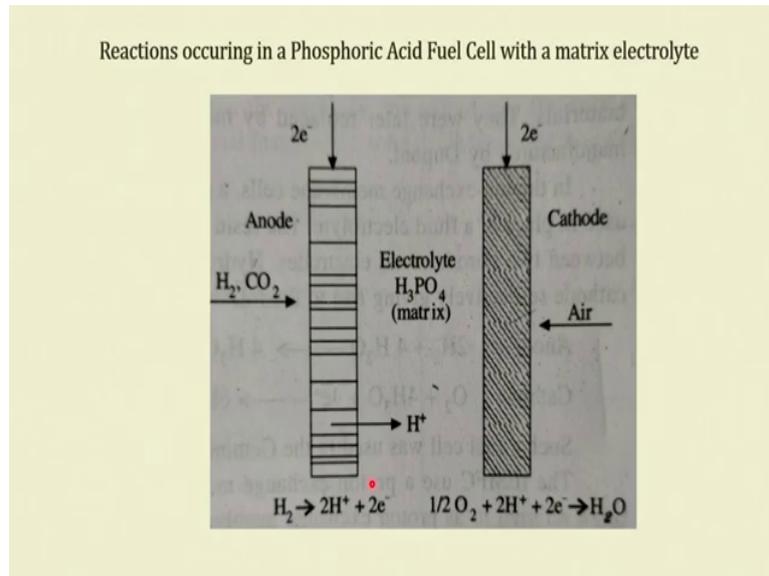
2. Molten Carbonate Fuel Cells (MCFC)



Coal - fueled MCFC power plants have been developed by International Fuel Cells (IFC) for electric utility and dispersed power generation.

So, what will be the outcome of soda that is what you drink at home bicarbonate so, carbon dioxide and water. So, products are always harmless especially, in fuel cells that to in molten carbonate fuel cells. So, cathode reaction we write $\frac{1}{2} \text{O}_2 + \text{CO}_2 + 2\text{e}^- \rightarrow \text{CO}_3^{2-}$ and $\text{CO} + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{CO}_2$. So, coal fuelled MCFC power plants have been developed by International Fuel Cells for electrical utility and dispersed power generation.

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Then there are reactions occurring in a phosphoric acid plant with a fuel cell with matrix electrolyte. Here I have Phosphoric Acid matrix H_2 CO_2 comes here. And this is a sort of an electrode plate electrode, this is a assume another cathode and reactions are very simple, like what we have studied so far anywhere all the time only simple reactions like H_2 goes to 2H^+ plus and oxygen goes to water.

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3. Phosphoric Acid Fuel Cells (PAFC)

These are considered as the most advanced fuel cells after the alkaline fuel cells used in space-craft. Phosphoric acid fuel cells have been operated in a wide range of power out - put (1 KW to 5 MW)

The reaction occurring in PAFC with a matrix electrolyte are represented in figure. Phosphoric acid fuel cell electrodes contain a noble metal catalyzed onto a PTFE (teflon) bonded carbon applied on a graphic - cloth support.

So, phosphoric acid fuel cells are considered to be most advanced fuel cells after the alkaline fuel cells, they are used in spacecraft. So, they have been operated with a wide range of power output 1 kilowatt to 5 megawatts. So, we are not talking of small power requirement, but also in megawatts.

So, the reaction occurring here with a matrix electrolyte are represented. I have already shown you the figure and the electrolyte is contained in a silicon carbide matrix. You cannot have the like electrolyte liquid hanging around in space applications, they have to be incorporated into a solid substance.

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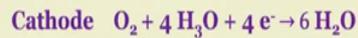
The electrolyte is contained in a silicon carbide matrix deposited on or placed between the electrodes. The bipolar plates are hot - pressed carbon or graphite plastic mixtures.

PAFC power plants using methanol as fuel were developed for U. S. army. Systems producing 20 KW on that basis were used for electric vehicle power plants.

So, that liquid is available all the time at the same time, it should not spill out and cause the corrosion and other related problems. So, the silicon carbide matrix is normally placed in between the electrodes. The bipolar plates are normally hot-pressed carbon or graphite plastic mixture. So, such fuels are developed for U.S. army, they have reached India, but we do not produce them in India.

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4. Ion Exchange Membrane Fuel Cells (IEMFC)



The general Electric Company has also developed a regenerative SPE-PEM (Solid Polymer electrode- proton exchange membrane) electrolysis - fuel cell system for space station applications. While in orbit, during shady periods, the fuel cell provides energy for the space station and during sunny periods, the output of the solar cells electrolyze the water formed in the fuel cells. The hydrogen and oxygen thus generated are supplied to the fuel cells again.

And we have also tried using them in electric vehicles and then power plants etcetera, but it is a slightly difficult right now to adopt them on a larger scale, because the technology has not been available. And as far as fuel cell technology is concerned, India is sort something like underdeveloped country.

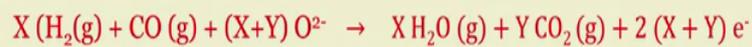
So, let us discuss a little bit about Ion Exchange Membrane Fuel Cells. These are also very simple systems essentially same reactions what we have discussed earlier. This is developed by GEC General Electric Company and Solid Polymer Electrode has been used. See these solid polymer electrodes these are all patented products which are not available in the free domain that is why all these applications make the space travel space applications very costly.

We have to import them and pay in Dollars. While in orbit, during shady periods they have actually fuel cell provides energy for the space station; that means, power required would be huge and during sunny periods of course, one can go for solar cells.

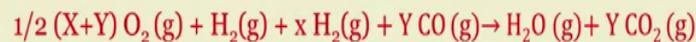
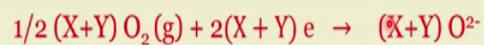
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5. Solid Oxide Fuel Cells (SOFC)

Anode reaction

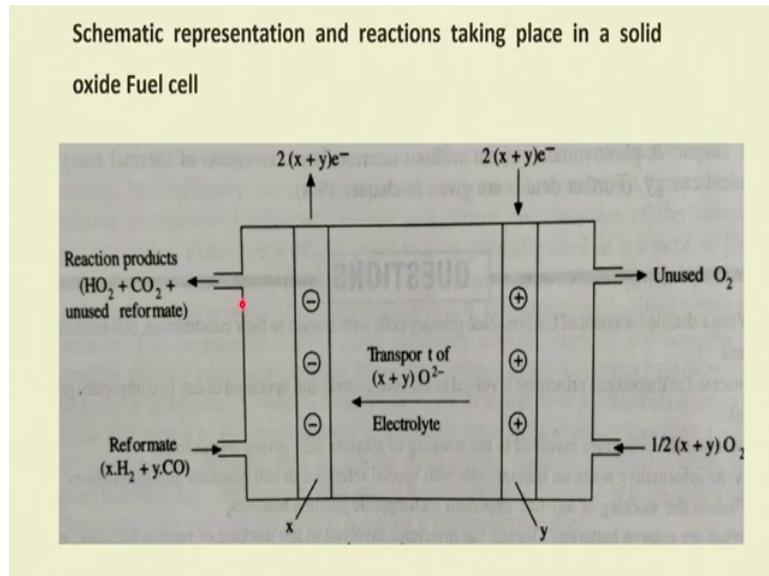


Cathode reaction



Then there are solid oxide fuel cells. A very simple reaction as usual X moles of H₂ plus CO plus X plus YO₂ minus goes to water CO₂ and e⁻ simple reaction cathodic oxygen plus electron goes to O₂ minus that will combine with water to give you water and CO₂. I have put X and Y to indicate that the quantities can be varying there than the stoichiometric requirement.

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So, a fuel cell requirement is again and the 1 electrode here, 1 electrode here. This is cathode, this is anode and the transfer electron of the electrons takes place in the in between the electrodes. We have a unused oxygen you we supply oxygen on one side and hydrogen on the other side. So, biochemical fuel cells are also there which will normally having specialized applications.

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6. Biochemical Fuel Cells

In biochemical fuel cells, organic substrates (eg. Urea and glucose) act as a fuel which is oxidised with the help of living organisms such as bacteria or enzymes derived from bacteria. These function as bio - anodes. It is also possible to accomplish direct reduction of oxygen or some other oxidant at the cathode (biocathode). In the indirect approach, the biological system can be used to generate reactants that are consumed at the electrodes.

For example, urea and glucose very simple reactions, but they act as a fuel which is oxidized with the help of living organisms biochemical cells. So, what are the living organisms that can oxidize substances? Everyone including us we oxidize glucose to survive bacteria's also do the same thing enzymes derived from bacteria are basically, the catchers of glucose and then they release the oxidation products.

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7. Regenerative Fuel Cells

In such cells, the fuel after it has been consumed to produce electricity, is regenerated and reused. For instance, photogalvanic cell, a chemical like nitrosyl chloride (NOCl) is photochemically dissociated into nitric oxide (NO) and chlorine, which are used as fuel in fuel cells. The fuels are regenerated photochemically.

So, it is possible to accomplish direct reduction of oxygen or some other oxidant at the cathode that is biocathode. So, they can be used to generate reactants that are consumed at the electrodes itself. Then there are Regenerative Fuel cells. Here, the photogalvanic cell is something like a chemical nitrosyl chloride is a photochemically dissociated into nitric oxide and chlorine which are used as fuel in fuel cells.

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8. Solar Cells

Direct or diffuse solar energy can be converted with the help of solar cells directly into electric current and photovoltaic current without intermediate conversion of thermal energy into mechanical energy.

The fuels are regenerated photochemically that is very interesting and now last one Solar Cells. Direct or diffuse solar energy can be converted with the help of solar cells, directly into electric current and photovoltaic current without intermediate conversion of thermal energy. This principle everybody knows is not it.

Nowadays we have all over the world solar energy available and solar panels etcetera very highly developed, but the problem is with higher energy conversion is still a dream as far as solar energy is concerned.

Normally we expect solar energy to be very efficient unfortunately, it is not. Maximum solar energy conversion what we have obtained so far in our research laboratory is approximately

about 19 percent. Not more than that, but 90 percent of the solar energy conversion units give you only about 13 to 14 percent if they cross 14, it is considered to be simply a super panel.

So, with this we come to the discussion on the electrochemical cells and in the next class that is our last class, we will talk about process waste handling and Zero electrical Zero liquid discharge systems.

So, thank you very much, we will meet again.