

Membrane Technology
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Lecture-28

Ion-exchange membranes, ED process, energy requirement, applications, reverse ED

Good morning students today is lecture 28 and then under module 10. So, in this module we will be discussing basically electro dialysis, pervaporation and we will solve a few problems based on these 2 topics. So, in today's class is exclusively dedicated to ion exchange membranes and electro dialysis.

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Ion-exchange membrane

- An ion-exchange membrane is a semi-permeable membrane which allows the passage of certain dissolved ions while retaining other ions.
- The basic desirable characteristics of ion-exchange membranes are as follows:
 - High permeability for oppositely charged ions
 - High ion permeability i.e. low electrical resistance (i.e. conductivity to counter ions and does not unduly restrict their passage)
 - High form stability or low degree of swelling
 - Mechanically strong and robust
 - Must not wrinkle or deform under thermal stress



So, let us begin so we have discussed in our earlier class what is ion exchange membrane? So, we have learned what are the different types of ion exchange membrane? So, we will just quickly go through this so that you can revise what we have been discussed earlier also. So, an ion exchange membrane is a semipermeable membrane that allows the passage of certain dissolved ions while retaining other ions.

So selectively it will pass certain ions resolved ends whereas retaining the other ions. So, the basic desirable characteristics of ion exchange membrane are as follows high permeability of oppositely charged ions. So, oppositely charged ions all of them must pass through the membrane which is actually eventually not happened in a real life system then high ion

permeability that is low electrical resistance that means conductivity to counter ions and does not unduly restrict their passes.

High form of stability or low degree of swelling a mechanically strong and robust and must not wrinkle or deform under thermal stress so these are some of the features of the ion exchange membranes.

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Ion-exchange membrane

- The membranes used in electro dialysis process are essentially consisted of sheets of ion-exchange polymeric resins.
- They may also contain other polymers to improve mechanical strength and flexibility.
- In the interstices of the polymer are mobile counter-ions. The resin components of a cation-exchange membrane would have negatively charged groups (eg. $-\text{SO}_3^{2-}$) chemically attached to the polymer chains.
- Ions with a charge opposite to the fixed charge (i.e. counter ions) are freely exchanged at these sites.



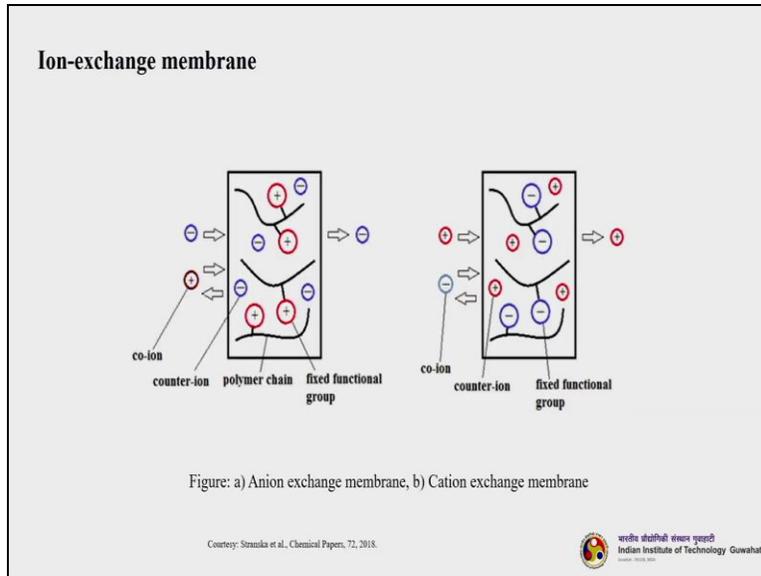
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Now the membranes used in electro dialysis process are essentially consisted of sheets of and exchange polymeric resins so they may also contain other polymers to improve mechanical strength and flexibility. So, it may happen many times so their stack it may be a membrane having a particular ions imparted into that if it is cation exchange or it can may be an ion exchange it may be bipolar also we will discuss this later.

So, in between also there may be other layers of polymers fused in between to improve the mechanical strength and flexibility. So, in the interest assess of the polymer are mobile counter ions. So, the counter ions are in a mobile phase are placed in between the interstices of this polymers layers of polymers basically. The resin components of a cation exchange membrane would have negatively charged groups so that is anions.

So cation exchange means it is exchanging cations so it has fixed anion groups and anion exchange means it is exchanging anion states would have fixed cationic groups. So, these groups either positive groups cations or anions are fused together or attached together to the polymer regions by that there are different methods actually it are to do that, that also we will discuss later. So, ions with the charge opposite to the fixed charge are freely exist at these sites.

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So let us see this is the schematic representation of an anion exchange membrane and a cation exchange membrane as you can see this, this the first one is the anion exchange membrane. Here you can see this fixed cationic groups are present so it is exchanging anions that means anions are getting transported whereas the cations are fixed inside the polymeric resins. So, inside the polymeric resins the interest assess of the polymeric layers so these cationic groups are present in a mobile phase.

The case is same for the cation exchange membrane. So, here the anions are fixed and the cation is getting transported. So, this is how actually a cation exchange membrane or a anion exchange membrane works alright.

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Ion-exchange membrane

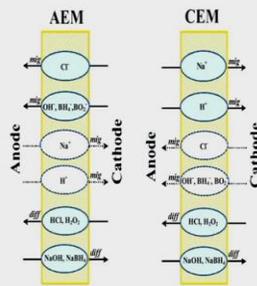


Fig. AEM and CEM in direct borohydride/peroxide fuel cells

Courtesy: Sipahi et al., Membranes, 2(3), 2012.



- Membranes operate according to the principle of Donnan exclusion, i.e., only transfer of oppositely charged ions is allowed (solid lines in Figure), while the transfer of ions of the same charge as the immobilized membrane group is mostly blocked (dotted lines in Figure).
- Since, the concentration of the counter ion is relatively high they carry most of the electric current through the membrane.
- The fixed charges attached to the polymer chains repel ions of the charge (co-ions), in this case the anions.
- Anions carry only a small fraction of the electric current through a cation permeable membrane as their concentration in membrane is relatively low.

So this is an example of a cation exchange and anion exchange membrane in a direct borohydride and peroxide fuel cell. So, you can see this de membranes how do these membranes operate so they operate by this donnan exclusion principle. So, membrane operate according to the principle of this donnan exclusion that means what is the meaning of that so that means only transport of oppositely charged ions is allowed.

So, you can see this in the first figure the solid lines the solid lines represent the oppositely charged migration of the ions through the membrane while the transfer of the ions of the same charge as immobilized membrane group is mostly blocked. So, this sodium you can see here potassium, so mostly they are blocked because they are oppositely charged. Since the concentration of the counter ion is relatively high they carry most of the electric current through the membrane.

So the fixed charges attached to the polymer chains repel ions of the charge that is coions in this case. Anions carries only a small fraction of the electric current through a cation permeable membrane is there concentration in membrane is relatively low. Now again; one more important thing that has to be remembered is this whenever we are talking about ion exchange membranes as we discussed that either cations anions are present in the mobile phase inside the membrane matrix.

So, how much amount of these cations or anions are present that also plays a big role in deciding the permeability or the transfer of the oppositely charged ions. So, this also plays a very big role the concentration of the ions. So, attached to the fixed charge that is R equals to CH₃ group actually to the polymer chains form anion permeable membrane which are selective to transport of negative ions because the fixed ammonia group repelled positive ions.

The meaning of donnan exclusion is really allowing the passes of opposite charged ions. So, the bulk solution contents a large excess of available sodium plus ions with an effectively constant concentrations. You can see this sodium ion is not getting properly transport through the membrane through the anion exchange membrane. So, a static layer of the solution known as the Nerst film surrounds the bead's ion transport takes place by diffusion only.

Strong convention that is high flow rate decreases film thickness. This is true for other membrane separation process also the ion concentration gradient occurs within it, diffusion through the film and in the solid phase of course at different rate.

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Ion-exchange membrane

- The two steps maybe rate determining:
 - Diffusion through ions within the resin (particle diffusion)
 - Diffusion in the Nerst film (film diffusion).
- Ion-exchange polymers such as poly (styrene sulfonic acid) are water soluble and so crosslinking is required to prevent dissolution of ion-permeable membranes.
- Divinylbenzene is used to crosslink polystyrene chains.
- Higher crosslinking improves the selectivity and membrane stability by reducing membrane swelling, but at the same time it reduces the electrical resistance.
- High charge density reduces resistance and increases the selectivity, but it promotes swelling and thus necessitates higher crosslinking.

2 steps may be rate determining in ion exchange membranes so the first is diffusion through ions within the resin. So, this is called particle diffusion and the second is diffusion in the Nerst film that is called film diffusion. Now ion exchange polymers such as polystyrene sulfonate acid are water soluble and are cross-linked. And so cross linking is required to prevent dissolution of ion

permeable membranes. Why we are talking about cross-linking because if you do the cross-linking then these charged groups will be almost permanently attached to the surface of the membrane or the polymers.

So, if it is not cross-linked properly then groups like sulphonic this polystyrene sulfonate dissolve they are water dissolve water-soluble. So, when you are using it for the desalination purposes most of these groups will come to the water side or to the aqueous medium. So, your ionic strength will initially though it will start then slowly, slowly it will decrease. Divinylbenzene is used to cross-linked polystyrene chains higher cross-linking improves the selectivity and membrane stability by reducing membrane swelling but at the same time it reduces electrical resistance also.

High charge density reduces resistance and increases the selectivity but it promotes swelling and thus necessitates higher cross-linking. So, higher cross-linking and higher charge density. So, you need to optimize it so some sort of optimization is required so that cross-linking is also good and charge density is also good.

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Ion-exchange membrane

- A compromise between selectivity, electrical resistance, and dimensional stability is achieved by proper adjustment of crosslinking and fixed charge densities.
- A typical electrodialysis membrane has a pore size of 10-20 Å with a capacity of 2-3 meq/g dw resin.
- Membrane thickness is of the order of 0.1-0.6 mm, and the electrical resistance is approximately 3 - 30 ohm/cm².

A compromise between selectivity electrical resistance and dimensional stability is achieved by proper adjustment of cross-linking and fixtures density. This is what I was just telling that some

sort of optimization is required to have a proper or good cross-linking as well as have pixel densities. A typical electro dialysis membrane has a pore size of 10 to 20 angstrom with a capacity of 2 to 3 milli covalent per gram dw resin. So, membrane thicknesses are of the order of 0.1 to 0.6 millimeter and the electrical resistance is approximately 3 to 30 ohm per centimeter square.

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Ion-exchange membrane

Based on distribution of fixed charges over the polymer matrix, ion-exchange membranes can be further classified as:

- (i) Homogeneous membranes,
- (ii) Heterogeneous membranes.



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So based on the distribution of fixed charges about the polymeric matrix and exchange membranes can be further classified into homogeneous membranes and heterogeneous membranes.

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Homogeneous membranes

In homogenous membrane, the fixed charges are distributed homogenously. They can be prepared by the following methods:

- a. Graft polymerisation of anionic or cationic moieties on to the molecular chains of the film.
- b. Polymerisation of mixture of reactants (eg. phenol, phenolsulphonic acid and formaldehyde) that can undergo condensation polymerisation.
- c. Introduction of anionic or cationic moieties into the polymer chain such as polysulphone, followed by the dissolution of the polymer and casting into the films.



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So, in homogenous membrane the peak states are distributed homogeneously they can be prepared by the following methods. So, graft polymerization of anionic or cationic moieties onto the molecular chains of the film or polymerization of mixture of reactants. So, in the first one directly the moieties that means the cationic and anionic groups the ions itself are being grafted on the surface of the polymer. So, in the second case it is a polymerization reaction so here mixture of reactants like let for example of phenol, phenol sulphonic acid formaldehyde, these are reacted and they form this cationic anionic groups.

So because they go they undergo the condensation polymerization reaction. Then another one is introduction of anionic or cationic moieties into the polymer chains such as poly sulfur followed by the dissolution of the polymer and casting into the films. So, these are the way how you can prepare homogeneous membranes,

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Heterogeneous membrane

The heterogeneous membrane can be ~~can be~~ prepared by incorporating ion-exchange particles into film forming resins by the following methods:

- a. Dispersion of the ion-exchange materials in a solution of the film forming polymer, followed by film casting, and solvent evaporation.
 - b. Dry moulding of mixtures of the ion-exchange and film forming materials.
- Homogeneous ion-exchange membranes have relatively low electrical resistance and high mechanical strength rendering them as better candidates for electro dialysis as compared to their heterogeneous counterparts.

The heterogeneous membranes can be prepared by incorporating ion exchange particles into film forming resins by the following methods so either you can have dispersion of the ion exchange materials in a solution of the film forming polymer followed by film casting and solvent evaporation. So, how do you actually repair the polymer solution how do you cast it then solvent evaporation all these things we have discussed during our membrane preparation technique so I am not repeating it.

So, then dry molding up mixtures of the ionic exchange and film forming materials, homogenous ion exchange membranes have relatively low electrical resistance and high mechanical strength rendering them as better candidates for electro dialysis as compared to their heterogeneous counterparts.

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Bipolar membrane

- Bipolar membrane consist of an anion permeable membrane and a cation permeable membrane joined together.
- When this composite structure is oriented in such a way that the cation-exchange layer faces the anode, it is possible by imposing a potential field across a membrane, to split water into proton and hydroxyl ions.
- This result in production of acidic and basic solutions at the surfaces of the bipolar membrane.
- Compared to the conventional electrolytic cells, the bipolar membranes are inexpensive.
- The bipolar membranes offers the prospect of (i) low cost and (ii) minimum unwanted by-products.
- The resistance of ion-exchange membranes is in range of 2-10 ohm/cm^2 and fixed charge density is about 1-2 $mequiv/g$.

Courtesy: ASTOM Corporation

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So, the next is bipolar membranes so they are very interesting actually so bipolar membrane consists of an anion permeable membrane and a cation permeable membrane joined together. So, there is a cation exchange membrane and the event exchange membrane they are joined together just see how it is being joined here. So, this is your anion exchange regime and this is your cation exchange resin or layer or membrane you can call them.

So when this composite structure is oriented in such a way that the cation exchange layer faces the anode. So, if you are fusing them then the cation exchange layer is facing the anion it is possible by imposing a potential field across the membrane to split water into proton and hydroxyl vessel. This is a classical example of water splitting reactions you can see water is getting split 2 protons and hydroxyl ions.

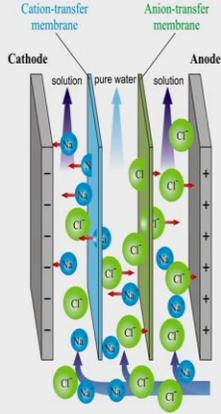
So, this result in the production of acidic and basic solutions at the surface of this bipolar membrane, now compared to the conventional electrolytic cells the bipolar membranes are inexpensive so that is why they are gaining a lot of attraction nowadays. The bipolar membrane

offers the prospect of low cost as well as minimum unwanted byproducts. So, here the byproduct formation is very, very less and the cost is also low so they are gaining more acceptance in industries. The resistance of ion exchange membrane is in the range of 2 to 10 ohm per centimeter square and fixed charge density is about 1 to 2 really equivalent per gram.

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Electrodialysis

- Electrodialysis, began in early 1900s as a modification to dialysis by the addition of electrodes and direct current to increase the rate of dialysis in electrolyte solutions.
- Electrodialysis, refers to an electrolytic process for separating an aqueous, electrolyte feed solution into a concentrate or brine and a dilute or desalted water (diluate) by means of an electric field and ion-selective membrane.



Courtesy: G. Eri "Electrodialysis," Croatian-English Chemistry Dictionary & Glossary 20 Oct. 2016.

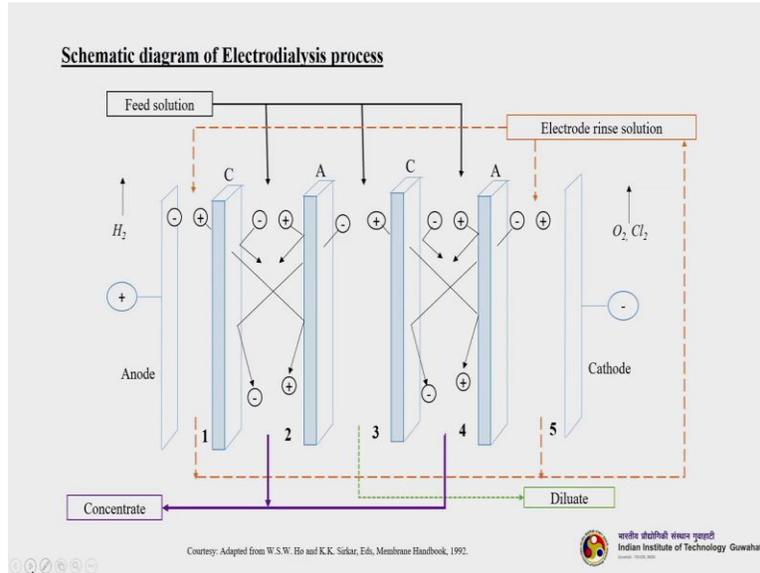
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Now let us discuss electro dialysis what is its concept so you can see closely look at this particular figure. So, electro dialysis actually began in the early 19th century as a modification to the dialysis by addition of electrodes. We have discussed what is dialysis now just imagine that dialysis is happening under the presence of an electrical gradient and there are 2 electrodes present one cathode and one anode, why do you do that, to increase the rate of dialysis in for a electrolyte solution.

Now electro dialysis refers to an electrolytic process for separating in aqueous electrolyte feed solution into a concentrate or brine and a dilute or desalted water by means of an electric field around selective membrane. So, you can see here this is a simple electrode diluate cell dialysis cell so here there is a cathode there is anode and there are 2 membranes one is cation transport membrane or cation exchange membrane another is anion transport or anion exchange membranes. So, you can see that feed is coming from here okay the seawater basically.

So, you can see that sodium's are getting transferred here in this chamber so it is getting concentrated here whereas chlorines are getting concentrated in this chamber particularly. And whatever water you are getting here so that is pure water because it is devoid of sodium chlorite now.

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So, this is a classical example of the schematic diagram of the electro dialysis process so, here there is a cathode there is a anode and I have shown here 4 stacks up for membranes for different types of membranes. So, you can see the C stands for the cation exchange membrane a stands for the anion exchange membrane again a cation exchange membrane. So, there are 2 stacks basically so in edie process a stack means one cation exchange membrane one anion exchange membrane and then maybe a cathode and anode.

Now the cathode and anode may be same so in between we can have many cation exchange minutes and anion exchange number and here I have shown you 4. So, here are 2 cation exchange membranes and 2 anion exchange membranes arranged in series something like this. Then your feed solution actually bring circulated here so this is feed it is entering here and this is compartment 1, this is compartment 2, this is compartment 3, this is compartment 4, this is compartment for 5th.

So, the concentrated solution we are getting in compartment 1 a compartment 2 and compartment 4 whereas the dilute solution is can dilute that is devoid of your ions basically we are getting from a compartment number 3.

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Electrodialysis

- The figure demonstrates a typical electrodialysis process, where the four ion-selective membranes shown are of two types arranged in alternating series pattern.
 - The cation-selective membranes 'C' carry a negative charge and thus attracts and pass positively charged ions (cations), while regarding negative ions.
 - The anion selective membrane 'A' carry a positive charge that attracts and permits passage of negative ions (anions).
- Both types of membranes are impervious to water.
- The net result is that both anions and cations are concentrated in compartment 2 and 4, from which the concentrate is withdrawn and the ions are depleted in compartment in 3, from which the diluate is withdrawn.



So, let us see the discussion so this figure demonstrates a typical electro dialysis process where 4 ion selective membranes shown are of 2 types arranged in alternating series pattern. So, the cation selective membrane carry a negative charge and thus attracts and pass positively charged ions well as regarding the negative ions. So, here a cation selective membrane C this C okay, so it carries, so, C is carrying a negative charge.

So, it is passing cations that mean it has a negative charge, so these are negative charge. So, it is passing cation that is why like similarly a anion exchange membrane it carries positive charge. So, what it is doing it is passing here anions so you can see the anion are passing here, here the cations are passing so cation exchange membrane is exchanging or passing the cations and anion exchange membrane is passing the anions.

So both cations and anions in a stack of 2 membranes all the ions are getting concentrated here. So, you get concentrated solution here, similarly we get concentrated solution here, all the concentrates are here then coming and getting collected here and in this particular this one stack

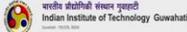
or a space the chamber 3 you can see hardly any ions are there because whatever the ions are coming here the feed sodium chloride.

So the cations are passing through this cation exchange membrane here the anions are passing through this membrane. So, here there is anode and there is a cathode and the electrical potential is applied.

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Electrodialysis

- The figure demonstrates a typical electrodialysis process, where the four ion-selective membranes shown are of two types arranged in alternating series pattern.
 - The cation-selective membranes 'C' carry a negative charge and thus attracts and pass positively charged ions (cations), while regarding negative ions.
 - The anion selective membrane 'A' carry a positive charge that attracts and permits passage of negative ions (anions).
- Both types of membranes are impervious to water.
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So, both types of membranes are impervious to water so this is important. So, the net result is that both anions and cations are concentrated in compartment 2 and 4 from which the concentrate is withdrawn and the ions are depleted in compartment 3 from which the diluent is withdrawn.

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Electrodialysis

- The compartment pressures are essentially equal.
- Compartment 1 and 5 are bounded on the far sides by the anode and cathode respectively.
- A direct current voltage is applied across the anode and cathode, causing current to flow by metallic conduction of electrons through the cell by ionic conduction from cathode back to the anode.
- Both electrodes are chemically neutral metals, with the anode being typically stainless steel and the cathode typically platinum-coated-tantalum, niobium, or titanium.
- Thus, the electrodes are neither oxidised or reduced.

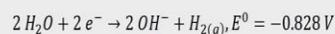


The compartment pressures are equally are essentially equal a compartment 1 and 5 are bounded on the 4 sides by anode and cathode respectively so a direct current voltage is applied across the anode and cathode causing current to flow by metallic conduction of electrons through the cell by ionic conduction from cathode back to the anode. Both electrons are chemically neutral metals with the inner being typically stainless steel and the cathode is typically platinum coated tantalum, niobium or titanium thus the electrodes are neither oxidized or reduced.

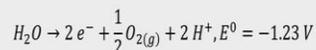
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Electrodialysis

- Typically, the most easily oxidised species is oxidised at the anode, and the most easily reduced species is reduced at the cathode.
- With inert electrodes, the result at the cathode is the reduction of water by the half reaction



- The oxidation half reaction at the anode is:



- or, if chloride ions are present:



where, the electrode potentials are the standard values at 25 °C for one molar solution of ions and partial pressures of one atmosphere for the gaseous products.



Typically the most easily oxidized species is oxidized at the anode and the most easily reduced species is reduced as the cathode at the cathode is the reduction of water by half reaction. So, you can see this direction to water plus 2 electrons giving 2 hydroxyl ions plus hydrogen in the form

of gas. The oxidation half reaction at the anode is water giving 2 electrons plus half oxygen in the form of gas plus 2 protons. So, if chloride ions are present so this is important again most of the times chloride ions are present.

So, 2 chlorine giving 2 electron plus chlorine in the form of gas whether electrode potentials are standard values at 25 degree centigrade for one molar solution of ions and partial pressures of one atmosphere for the gaseous product.

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Electrodialysis

- Values of E^0 can be corrected for non-standard conditions by the Nernst equation. The corresponding overall equation can be written as:

$$3 H_2O \rightarrow H_{2(g)} + \frac{1}{2} O_{2(g)} + 2 H^+ + 2 OH^-$$

or,

$$2 H_2O + 2 Cl^- \rightarrow 2 OH^- + H_{2(g)} + Cl_{2(g)}, E_{cell}^0 = -2.058 V$$

- The net reaction for the first case is:

$$H_2O \rightarrow H_{2(g)} + \frac{1}{2} O_{2(g)}, E_{cell}^0 = -2.188 V$$

- The electrode rinse solution that circulates through compartments 1 and 5 is typically acidic to neutralise the OH^- ions formed in compartment 1 and prevent precipitation of compounds such as $CaCO_3$ and $Mg(OH)_2$.



So value of E can be a character for non-standard conditions by the non Nernst equation and the corresponding overall equation can be written as 3 waters giving hydrogen in the form of gas plus half oxygen in the form of gas plus 2 protons + 2 hydroxyl ions or 2 water + 2 chlorine if chlorine is present gives 2 hydroxyl ions plus hydrogen in the form of gas plus chlorine in the form of gas the net reaction for the first case is water is splitting into hydrogen in the form of gas plus half oxygen in the form of gas.

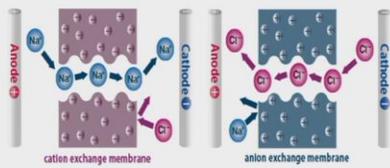
So, electrode range solution that circulates through compartment 1 and 5. So, just trying to show you again there is something called the electrode Erne's solution noted by this red line you can see this so this electrode range solution is actually circulated through compartment 1 and 5 is typically acidic what is its job so it has to neutralize the OH^- ions firmly in the

compartment one and prevent precipitation of compounds such as calcium carbonate and magnesium hydroxide.

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Electrodialysis Membranes

- The most widely used ion-exchange membrane for electrodialysis (first reported by Juda and McRae, in 1950) are:
 - Cationic-selective membrane containing negatively charged groups fixed to a polymer matrix, and
 - Anion-selective membranes containing positively charged groups fixed to a polymer matrix



The diagram illustrates the structure of two types of ion-exchange membranes used in electrodialysis. On the left, a cation exchange membrane is shown with a polymer matrix containing negatively charged groups (represented by blue circles with minus signs). Sodium ions (Na⁺) are shown moving from the anode (left) towards the cathode (right) through the membrane. On the right, an anion exchange membrane is shown with a polymer matrix containing positively charged groups (represented by red circles with plus signs). Chloride ions (Cl⁻) are shown moving from the anode (left) towards the cathode (right) through the membrane. The electrodes are labeled 'Anode (+)' and 'Cathode (-)'. The IIT Guwahati logo is visible in the bottom right corner.

So, as you know that we have different types of membranes so he can have cation exchange membranes which as having a negatively charged fixed groups and anion exchange membranes which is having positively charged fix groups for the electro dialysis membrane purposes.

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Electrodialysis Membranes

- A typical cation-selective membrane is made of polystyrene cross-linked with di-vinylbenzene and sulfonated to produce fixed sulfonate, $-SO_3^-$ anion groups.
- An anion selective membrane of the same polymer contains quaternary ammonium groups such as $-NH_3^+$.
- Membranes are 0.2-0.5 mm in thickness and reinforced with a screen to provide mechanical stability.
- The membranes which are made in flat sheets contain 30-50% water and have a network of pores too small to permit water transport.



The IIT Guwahati logo is located in the bottom right corner of the slide.

A typical cut and selective membrane is made up of polystyrene cross-linked with dye divinylbenzene and sulphonated to produce fixed sulfonate groups SO_3^- anion groups. And anion selective membrane of the same polymer contents quaternary ammonium group such as NH_3^+

plus membrane at 0.2 to 0.5 mm thickness and reinforced with screen to provide mechanical stability. Mechanical stability is very important because when you are going for a continuous operation so the stability of the membrane also has to be taken care of because there is some pressure is always that is getting developed inside the electro dialysis cell though we are not pressure driving the system.

However to withstand the thermal mechanical all these types of pressures so the stability of the membrane is very important, so the membranes which are made in flat sheets content 30 to 50% of the water and have a network of ports too small to permit water transport.

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Electrodialysis

- A cell pair or unit cell consists of one cation-selective membrane and one anion-selective membrane.
- A commercial electro dialysis system is a large stack of membrane patterned after a plate-and-frame configuration.
- In a stack, membranes of from 0.4-1.5 m² surface area each are separated by from 0.5-2 mm with spacer gaskets.

Logo of Indian Institute of Technology Guwahati

A cell pair or a unit cell consists of one cation elective selective membrane and one anion selective membrane, so, one cation selective one and selective and one cathode. So, basically one cation selective one anion selective then one cathode and one anode, so, this is what is called a pair or unit cell of a single electro dialysis system basically. So, commercial electro dialysis system is a large stack of membranes patterned after a plate and frame configuration.

So, for a commercial system we have C A C A C A C A like this alternatively in series. Then we have here anode and we will have here cathode. So, you applied electric potential and then do the separation number now please you remember that we cannot increase the number of the cation

exchange membrane and an exchange membrane just infinitely with a single cathode and single anode that is not possible. So, there is always a optimization that you have need to do it.

With a single anode and a single cathode maximum number of cell pairs you can have for our targeted separation. So, in stack membranes of 0.4 to 1.5 meter square surface area each are separated from 0.2 to 2 mm with special gaskets.

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Electrodialysis

- The total voltage or electrical potential applied across the cell includes:
 - i. the electrode potentials discussed earlier,
 - ii. over-voltages due to gas formation at the electrode,
 - iii. the voltage required to overcome ohmic resistance of the electrolyte in each compartment,
 - iv. the voltage required to overcome resistance in each membrane,
 - v. the voltage required to overcome concentration polarisation effect caused by mass-transfer resistances in electrolyte solution adjacent to membrane surface.
- For large stacks, the latter three voltage increments predominates and depend upon the current density (i.e. the amps flowing through stack per unit surface area of membranes).



The total voltage or electrical potential applied across the cell includes the electrode potentials that we have discussed earlier. Over voltage due to gas formation at the electron, the voltage required to overcome ohmic resistance of the electrolyte in each compartment. The voltage required to overcome resistance in each membrane. The voltage required to overcome concentration polarization effect caused by mass transfer resistance in electrolyte solution adjacent to membrane surface.

And for large stacks the latter 3 voltage increments predominates and depend upon the current density that is the amps following through the stack per unit surface area of the membranes.

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Electrodialysis

- A typical voltage drop across a cell pair is 0.5 - 1.5 V.
- Current densities are in range of 5 - 50 mA/cm².
- Thus, a stack of 400 membranes (200 unit cells) of 1 m² surface area each might require 200 V at 100 A.
- Typically, 50-90% of brackish water is converted to potable water, depending on concentrate recycle.
- As the current density is increased for a give membrane surface area, the concentration polarisation effect increases.

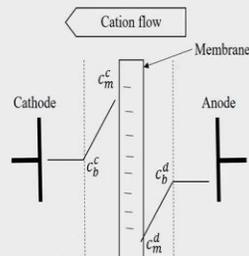


A typical voltage drop across a cell pair is about 0.5 to 1.5 volt current densities are in the range of 5 to 50 milli ampere per centimeter square thus a stack of 400 membranes so basically 200 unit cells up 1 meter square surface area each might require 200 volt at 100 amperes. So, typically 50 to 90% of blackish water is converted to potable water depending on constant at recycle. If the current density is increased for a give for a given membrane surface area the concentration polarization effect increases.

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Electrodialysis

- Concentration polarisation effect for a cation-exchange membrane



where, c_m refers to cation concentration in the membrane, c_b refers to bulk electrolyte cation concentration. The d and c refers to the dilute and concentrated side respectively.

Courtesy: H. Strathmann, Sep and Purif Methods, 14(1), 41-66, 1985.



So, concentration polarisation effect for a cation exchange membrane is zone here so he has c_m refers to the cation concentration in the membrane c_b refers to the bulk electrolyte cation concentration the d and c refers to the dilute and concentrated side respectively.

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Electrodialysis

- The maximum or limiting current density is reached when the c_m^d reaches zero.
- Typically, an electro dialysis cell is operated at 80% of the limiting current density which is usually determined by experiment.
- The corresponding cell voltage or resistance is also determined experimentally.
- The amount of gases formed at the electrodes at the two end of stacks are governed by the *Faraday's law of electrolysis*.
- During electrolysis, one *Faraday* (96520 coulombs) of electricity reduces at cathode and oxidises at anode an equivalent of oxidising and reducing agent corresponding to transfer of 6.023×10^{23} (Avogadro's number) electrons through wiring from anode to the cathode.



The maximum and limiting current density is reached when the c_m in dilute side reaches zero typically in electro dialysis cell is operated at 80% of the limiting current density which is usually determined by experiment. The corresponding cell voltage or resistance is also determined experimentally. The amounts of gases formed at the electrodes at the 2 end of stacks are governed by the Faraday's laws of electrolysis.

So during electrolysis one Faraday's that is exactly equal to the 96520 coulombs of electricity reduces at cathode and oxidizes at anode an equivalent of oxidizing and reducing agent corresponding to transport of 6.023×10^{23} that is the Avogadro's number of electrons through varying from anode to cathode. So, this is the amount of electricity that is getting passed.

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Electrodialysis

- In the design and operation of electro dialysis membrane process, the membrane area and electrical energy requirement are important.

- The membrane area is estimated from the current density, by applying Faraday's law: $A_m = \frac{FQ\Delta c}{i\xi}$

where, A_m = total area of all cell pairs, m^2 ,

F = Faraday's constant (=96520 amp-s/equivalent),

Q = volumetric flow rate of the diluate (potable water), m^3/s ,

Δc = concentration difference between feed and diluate ion concentration (in *equivalents/m³*),

i = current density (in amps/m² of a cell pair),

ξ = current efficiency (< 1.00)



In the design and operation of electro dialysis membrane process the membrane area and electrical energy requirement are important. In the membrane area is estimated from the current density by applying Faraday's law so this is the equation. So, A_m equals to $F Q \Delta C$ by i Zeta where m is the total area of all cell pairs in meter square, F is Faraday's constant, Q is volumetric flow rate of the diluents so which is actually the potable water in meter cube per second, ΔC is the concentration difference between the predilute ion concentration in equivalence per meter cube, i is current density in amperes per meter square of the cell pair and Zeta is the current efficiency which is usually less than 1.

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Electrodialysis

- The last variables accounts for the fact that not all of the current is effective in transporting the selected ions through membranes.
- Inefficiencies are caused by a Donnan exclusion of less than 100%, some transfer of water through the membranes, the current leakage through manifolds, etc.
- The power consumption is given by:

$$P = IE$$

where,

P = power (in W),

I = electric current flow through the stack (in *amp*),

E = voltage across the stack (in V)



So the last variable accounts for the fact that not all of the current is effective in transporting the selected ions to the membrane. Now inefficiencies are caused by this Donnan exclusion of less than 100% some transport of water through the membranes and current leakage to the manifold. So, you devise any sorts of membrane basically as we have discussed that most these membranes are impermeable to water but in actual practice when there is some pressure developed inside the membrane. So, some inside the system so some water passes through that is against the principle of 100% Donnan exclusion and there are leakages and other things also.

So, power consumption can be calculated by P equals to I into E so P is the power in watts I is electric current flowing through the stacks in amperes E is the voltage across the stack in volt.

(Refer Slide Time: 25:26)

Electrodialysis

- The electrical-current flow is given by:

$$I = \frac{FQ\Delta c}{n\xi}$$

- The main application of the electro dialysis is to the desalination of brackish water in the salt concentration range of 500 - 5000 ppm.
- Below this range, ion-exchange is more economical whereas above this range to 50,000 ppm, reverse osmosis is more preferred.
- However, electro dialysis cannot produce water with a low dissolved solid content because of the high electrical resistance of dilute solutions.



The electrical flow is given by I equals to F Q Delta C by n Zeta so the main application of the electro dialysis is to desalinate brackish water in the salt concentration of usually 500 to 5000 ppm. Now below this range sub that means below 500 ppm ion exchange is more economical and about 50,000, reverse osmosis is better this we have discussed in reverse osmosis also. However electro dialysis cannot produce water with a lower dissolved solid content because of the high electrical resistance of the dilute solutions.

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Electrodialysis

- Other applications include:
 - recovery of nickel and copper from electroplating rinse water; deionisation of cheese whey, fruit juices, wine, milk and sugar molasses,
 - Separation of salt, acids, and bases from organic compounds, and recovery of organic compounds from their salts.
- Bipolar membranes prepared by laminating a cation-selective and anion-selective membrane can be used to produce sulphuric acid and sodium hydroxide from a sodium sulphate solution.



So, apart from desalination of brackish water there are other applications also so recovery of nickel and copper from electroplating range water at deionization of cheese, whey, fruit juices wine milk and sugar molasses, separation of salt acids and bases from organic compounds and recovery of organic compounds from their salts. Bipolar membranes prepared by laminating a cation selective and anion selective membrane can be used to produce sulfuric acid and sodium hydroxide from a sodium sulphate solution.

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Energy requirement, current utilisation, efficiency

- The energy required for the removal of salts from a feed solution is directly proportional to the total current flowing through the stack and the voltage drop between the two electrodes in a stack.
- According to the basic electrical equation of Ohm:

$$V = IR \quad (i)$$

where, V = voltage (volts), I = current (amp), R = Resistance (ohm)

- Again, $I = \frac{Q}{t}$ (ii)
where, Q = charge (coulombs), t = time

- and, $E = V.I.t$ (iii)

where, E = Energy consumption (Joules)



Now let us understand the energy requirement current utilization and efficiency. The energy required for the removal of salts from a feed solution is directly proportional to the total current flow flowing through the stack and the voltage drop between the 2 electrodes in a stack. So,

according to the basic equation of the ohm V equals to $I R$ so V is voltage in volts I is current in ampere R is resistance in ohm. So, again I is nothing but Q by t so Q is the charge in coulombs and t is time and equals to $VI t$ so E is energy consumption I your current and t is your time.

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- Combining, equation (i-iii) for 'n' number of unit cells in a stack:

$$E = I^2 n R t \quad (iv)$$

- Since, resistance in the dilute and concentrated parts of the cell differs from each other, the resistance per unit cell R can be taken as an average cell resistance.

- Therefore,

$$E = I^2 n t (R_{conc} + R_{dil}) / 2 \quad (v)$$

- If each chamber is completely mixed. In general the resistance is approximately inversely proportional to the concentration.

$$R = b / c \quad (vi)$$

where, b is constant, and c is in equivalent s/l .



So, if you combine these 3 equations for n number of unit cells so we can write E equals to I square $n R t$ since resistance in that dilute and concentrated parts of the cell differs from each other the resistance per unit cell are can be taken as an average cell resistance. So, therefore E equals to I Square $n t$ so R concentrated plus R dilute divided by 2. So, if the chamber is completely mixed so in general resistance is approximately in inversely proportional to the concentration R equals to b by c where is b is a constant and c is your concentration.

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Energy requirement, current utilisation, efficiency

- After some algebraic manipulation we get,

$$E = \frac{I^2 n t R(c_f)}{\frac{2c_{dil}}{c_f} - \left(\frac{c_{dil}}{c_f}\right)^2} \quad (vii)$$

where, $R(c_f)$ is the resistance per cell determined at the feed concentration.

- Further, electric current needed to desalt a solution is directly proportional to the number of ions transferred through the membrane.
- It can be expressed as:

$$I = \frac{z F Q (C_f - C_{dil})}{\xi} \quad (viii)$$

where, F = Faraday's constant, z = electrical valance, Q = volumetric flow rate, $(C_f - C_{dil})$ = concentration difference between the feed solution and diluate, ξ = current utilisation.



So after some algebraic manipulation we will get in this equation equals to $I^2 n t R c_f$ divided by $c_f - c_{dil}^2$ where c_f is the resistance per cell determined at the feed concentration. Further electric current needed to desalt a solution is directly proportional to the number of ions transport through the membrane it can be expressed as I equals to $z F Q (C_f - C_{dil})$ by ξ where F is Faraday's constant z 's electrical balance Q is volumetric flow rate $C_f - C_{dil}$ is concentration difference between the feed solution and the diluate and ξ is the electrical utilization.

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Energy requirement, current utilisation, efficiency

- The current utilisation (ξ) is the most important term in the equation (vii).
- It is directly related to the number of cells 'n' in a stack and the efficiency of utilisation of current.
- Combining equation (v) and (viii):

$$E = \frac{I n t R_{av} z F Q (C_f - C_{dil})}{\xi} \quad (ix)$$

where,

$$R_{av} = (R_{conc} + R_{dil})/2 \quad (x)$$

- The equation (ix) indicates that the electrical energy required in electrodialysis is directly proportional to the amount of salt that has to be removed from certain feed solution to achieve the desired product concentration.



So, the current utilization is the most important term in this equation it is directly related to the number of cells n in a stack and the efficiency of utilization of the current. So, if you combine

the equation 5 and 8 so he get equation something like this where R average equals to R concentrate plus R diluted divided by 2. Now this equation indicates that electrical energy required in electro dialysis is directly proportional to the amount of salt that has to be removed from each feed solution to achieve the desired product concentration.

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Energy requirement, current utilisation, efficiency

- Energy consumption is also a function of the number of cells in a stack and the electrical resistance in a cell.
- Electrical resistance again is a function of individual resistances of the membrane and of the solution in the cell.
- The current utilisation is directly related to the number of the cells 'n' in the stack and the efficiency of utilisation of current.

$$\xi = n\eta_s\eta_w\eta_m \quad (xi)$$

where, n is the number of unit cells, η_s is the efficiency due to the semipermeable of the membrane (membrane constant), η_w is the efficiency related to water transfer through the membrane, η_m is the efficiency since some of the current invariably leaks through manifold holding the membrane.



So, energy consumption is also a function of the number of cells in a stack and the electrical resistance in his cell. Electrical resistance again is a function of individual resistances of the membrane and of the solution in the cell. Now the current utilization is directly related to the number of cells by this equation so you can write Zeta equals to n eta s eta w eta m so where n is the number of unit cells eta s is the efficiency due to the semi permeable of the membrane that is the membrane constant basically eta w is the efficiency related to water transport through the membrane.

And eta m is the efficiency since some of the current invariably leaks through the manifold holding the membrane. So, eta s is the semi permeability membrane thing eta w is the water transfer capability and this is about the current.

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Energy requirement, current utilisation, efficiency

- All the efficiencies are less than unity and overall electrical efficiency is about 0.9. But n varies from 100 to 600.
- The ξ is usually higher than unity.
- The membrane area for cation- and anion-exchange membrane can be estimated from:

$$A = \frac{FQn(C_f - C_{dil})}{i\xi} \quad (xii)$$

where, ' i ' is the current density (amp/cm^2). The membrane area, A is related to the area of each individual membrane, A_m given by:

$$A = n A_m \quad (xiii)$$

- The area A_m is set by dimension of the plate and frame module which are standardised by the manufacturers.



So, all the efficiencies are less than unity and the overall electrical efficiency is about 0.9 but n varies from 100 to 600 depends upon what type of commercial establishment it is. So, the Zeta is usually higher than unity the membrane area for cation and anion exchange membrane can be estimated from this equation equals to $FQn C_f - C_{dil}$ divided by $I \xi$ where I is the current density and the membrane area A is related to the area of each individual membrane given by A equals to nA_m where A_m is set by the dimensions of the plate and frame module which are standardized by the manufacturers.

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Energy requirement, current utilisation, efficiency

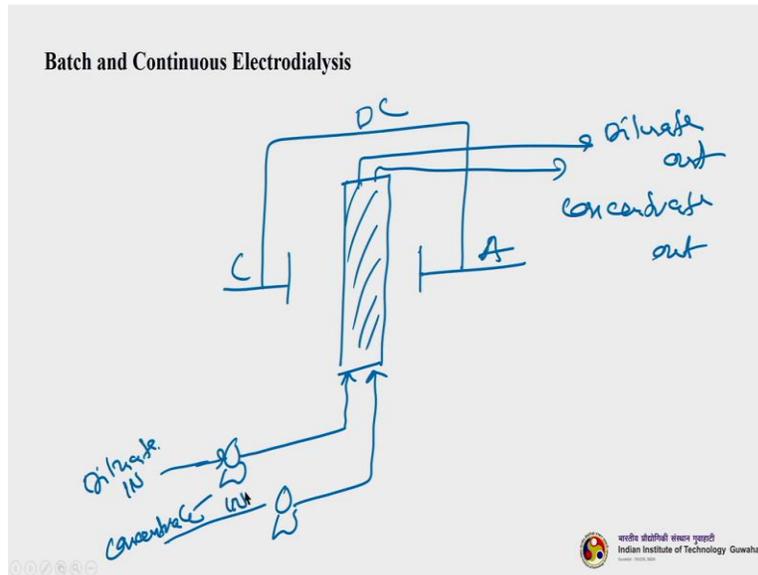
- Substituting the equation (ix) and (xiii) in (xii) we get:

$$n = \frac{FQ(C_f - C_{dil})}{I\eta_s\eta_m\eta_w} \quad (xiv)$$



So substituting we get this is the final equation n equals to $FQ C_f - C_{dilute}$ divided by $\eta I \eta_m \eta_w$.

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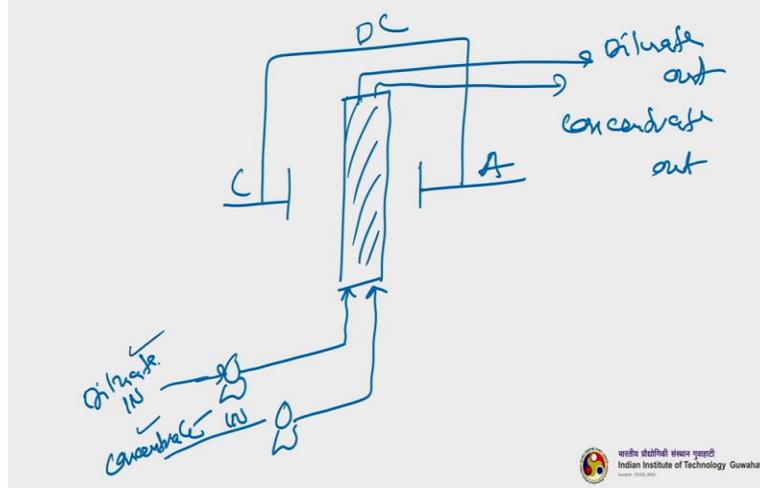
So, we can have our electro dialysis process operating in 2 modes either you can have a batch mode or you can have a continuous mode. Now batch mode are easy to operate that is true but the problem is that the pressure this one the power consumption will rise. Now let us see how we can have a batch operation so you can have a so let us say this is our electro dialysis membrane setup so then you will have a cathode here will have an anode here.

So of course cathode and anode are connected to a DC source. So, and then what will happen basically so you will be passing or pumping there is a feed tank here from which the feed is getting pumped and it is getting inside the membrane and there is another okay which is concentrate we you need another pump here to pump the concentrate here. So, what you will get from here is diluate and whatever you will get here is your concentrate.

So what is happening in this batch mode of system is actually the power consumption rises with the process because of the voltage drop over the cell increases. Now it is also possible to run an eddy process in a continuous mode also to decide whether we will have a batch mode or a continuous mode and the stack design has to be taken into account.

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Batch and Continuous Electrodesialysis



Now you can have this process in a continuous system also, I am just trying to draw a continuous system so again a cathode here again anode here so this is anode and this is cathode they are connected to a DC source alright so and then we will have a pump will have 2 pumps basically so this pump is pumping here this is your concentrate this is a dilute. So, you will get a dilute out here and you have a concentrate out and this is in and this is in.

So this is the continuous mode of operation it is easy to do that now you S-tech design and there are other operating parameters which will eventually decide whether you will go for a bi system or a continuous system. And now if you want to run the module electrodesialysis module in a continuous mode the module has to treat the solution in one go, why the batch in the batch process what is happening if you go back in the batch process.

What is happening so when you are passing and the diluent concentrate in a single stage what is happening that you are not at all getting your targeted separation order a targeted purity whatever you can call it. So, you have to pass the same solution the concentrator and dilute many times to achieve your target in the same membranes. So, it is going on in a best process but many times so eventually what is happening by doing so the power consumption rises okay.

Because there is a voltage drop over the ceiling increases so here in case of continuous system so this is not happening and it is necessary to assign a certain time and certain velocity of this

solution both dilute as well as concentrate and it is also important that the residence time in between in inside the electro dialysis cell is enough so that a proper separation is happening. So, this is how ED can be operated in batch and continuous mode.

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Application of Electrodialysis

Chemical industry:

- a. Desalination and conservation of sea, brackish and industrial waters: Electrodialysis is widely used in desalination of brackish water. In this process, the salts are concentrated to comparatively high values. The process is unique in Japan, whereby law it is used to produce essentially in all of its domestic table salts.
- b. Separation of inorganic and organic solutions.
- c. Purification of organic substances (such as amino acids).
- d. Wastewater treatment, and recycling of chemical substances: Electrodialysis, is an alternative process in treatment of wastewater, since it allows the reuse of process water and the recovery of metal ions, minimising or even avoiding the production of the galvanic sludge.
- e. Use in galvanic industries: In galvanic industry, electro dialysis can be used for regenerating the metal finishing baths and wastewater treatment.



Now let us understand the applications there are many applications the most important application is of course the desalination and conservation of sea blackish and industry waters. So, electro dialysis is widely used in desalination of brackish water where the concentration of the salt is usually 500 to 5000 ppm. So, in this process the salts are concentrated to comparatively high values the process is unique in Japan where by law it is used to produce the essentially in all of its domestic table salts by in the means of electro dialysis.

Then we can have separation of inorganic and organic. So, purification of organic substances such as amino acids then wastewater treatment and recycling of chemical substances so in electro dialysis it is an alternative process for treatment of wastewater since it allows the reuse of the process water. And this is the most important thing allows the reuse of process water in the recovery of metal ions minimizing or even avoiding the production of galvanic sludge.

So, this is very important thing. So then in galvanic industries; so in galvanic industry ED can be used for regenerating the metal finishing baths and wastewater treatment.

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Food industry:

- a. Demineralisation of cheese whey: Whey provides an excellent source of protein, lactose, vitamins, and minerals. However, it has high salt content. With the ionised salts substantially removed, whey approaches the composition of human milk and provides an excellent source for the baby food.
- b. Wine stabilisation: It involves removal of tartaric acid from wine. In the production of the bottled champagne, especially it is necessary to avoid the formation of crystalline tartar in the wine and tartaric acid must be reduced to a level that does not exceed the solubility limit.



So, apart from that in food industry the application is demon realization of cheese whey and wine stabilization. So, where provides an excellent source of protein lactose, vitamins and minerals however it has high salt content. So, with ionized salts substantially removed whey approaches the composition of human milk and provides an excellent source for the baby food. So, wine stabilization is another replication of electro dialysis process in your food industries.

So, it involves the removal of tartaric acid from wine so tartaric acid has to be removed from the wine in the production of the bottle sample essentially it is necessary to avoid the formation of crystal and tartar in the wine and tartaric acid must be reduced to a level that does not exceed the solubility limit. Otherwise it will form crystals and you can clearly see that there are some crystals getting deposited on the bottom of the wine bottle or champagne bottle.

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- c. Production of artificial mother's milk: When comparing mother's milk with cow's milk, the ash content is three times higher and the protein content is six times higher in cow's milk. Therefore, when cheese whey, the leftover after cheese protein is removed from cow's milk, and fresh cow's milk are combined. The protein content becomes almost equal to the mother's milk.
- d. Desalination of fruit juice
- e. Desalting of dextran solution

So, next in the food industry is the production of artificial mother's milk. Now when comparing mother's milk with cow's milk the s content is 3 times higher and the protein content is 6 times higher in cow's milk. So, therefore green cheese where the left over after the cheese protein is removed from cow's milk the fresh cows milk are combined them protein content become almost equal to the mother's milk. Then we have application in desalination of fruit juices and desalting up dextran solution.

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Pharmaceutical industry:

Purification of fermented solution, serum, and vaccines.

Other uses:

a. Regeneration and recycling of galvanic baths:

In the production of printed circuits, a chemical process is often used for copper plating. The component to be placed are immersed in a bath containing copper salt solution, formaldehyde, and EDTA. During this process, formaldehyde is oxidised to formate. After prolonged use, the bath becomes enriched with Na_2SO_4 , formate, loses useful properties. By applying electro dialysis in a continuous mode, the Na_2SO_4 , and formate can be selectively removed from the solution without affecting the concentration of formaldehyde and, and EDTA complex.

In the pharmaceutical industries also we have application in purification of fermented solution serum and vaccines. There are other uses just like regeneration and recycling of galvanic baths in the production of printed circuits a chemical process is often used for copper plating. The

component to be placed are immersed in a bath containing copper salt solution formaldehyde and EDTI. Now during this process formaldehyde is oxidized to formate after prolonged use the bath becomes enriched with sodium sulfate form it loses useful properties.

So, by applying electro dialysis in a continuous mode the sodium sulfate formate can be selectively removed from the solution without affecting the concentration of formaldehyde and EDTA complex.

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b. Purification of salty mine water:

There is a current need to evaluate the use of electro dialysis on the treatment of wastewater with the aim of scaling it up to industrial operation. However, it is important to understand the behaviour of such a system either in laboratory or pilot plant condition.

c. Recovery of valuable electrolytes: Electro dialysis can be successfully used in recovery of various electrolytes. It can recover pure $NaCl$ from seawater, $Ag(I)$ salts from photographic waste, $Ni(II)$ from electroplating rinse waters, $Zn(II)$ from galvanising rinse water, salts of organic acids from fermentation broth, amino acids from protein hydrolysates, acids from metal pickling baths, and rinse HCl from cellulose hydrolysate.



Then purification of salty mine water so there is a current need to evaluate the use of electro dialysis on the treatment of wastewater with the aim of scaling it up to industrial operation. However it is important to understand the behavior of such a system either in laboratory or pilot plant condition. Recovery of valuable electrolytes is another application. So, electro dialysis can be successfully used in the recovery of various electrolytes.

So it can recover pure sodium chloride from seawater then silver salts from photographic waste and then nickel from electroplating reuse waters, zinc from galvanizing means water salts up organic acids from fermentation broth, amino acids from protein hydrolysis, acids from metal pickling baths and reeds hydrochloric acid from cellulose hydrolysis. So, you can see that there are so many applications of electro dialysis.

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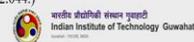
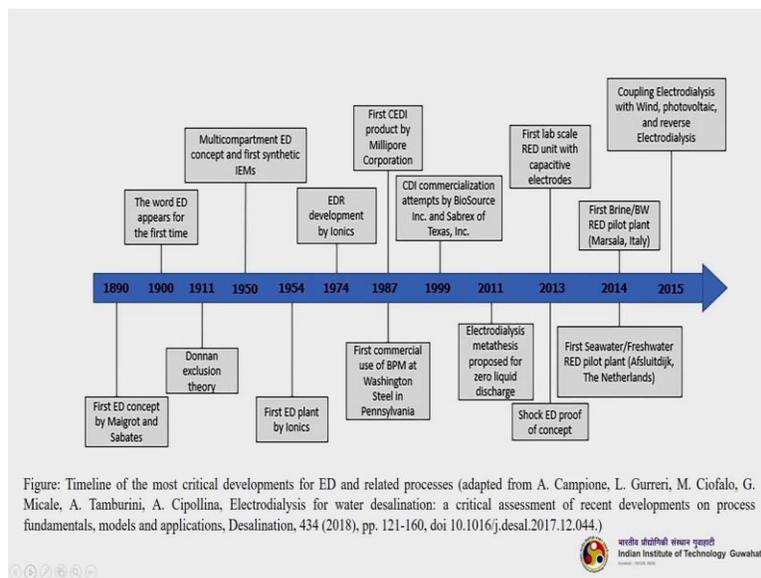
Some important applications of electro dialysis includes:

- Rinse water treatment from plating industry of metals like Chromium, Cadmium, and Nickel.
- Recovery and concentration of ions (e.g., $\text{NH}_4\text{-N}$, K , $\text{PO}_4\text{-P}$) from wastewater and supply the global demand of macronutrients.
 - This technique not only concentrates metals from rinse-waters, but it also maintains the quality of a plating bath.
- To concentrate nutrients from waste streams.



Some important applications further includes that range water treatment from plating industry of metals like chromium, cadmium, nickel recovery and concentration of ions from wastewater and supply the global demand of macronutrients. This technique not only concentrates metals from drainage water but it also maintains the quality of a plating bath that is also very important to concentrate then nutrients from waste stream.

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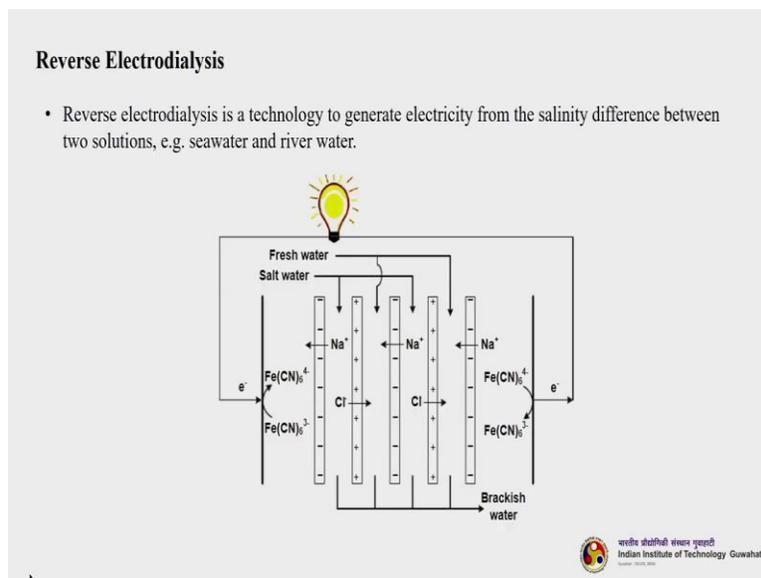
So, students this is taken from this one of the journal publications. So, just to show you and understand that the timely mean timeline of the most critical development of the electro dialysis process and related processes, so it started with 1890 long back you can see that the first ED

concept by Maigrot and Sabates, so these are the 2 scientists who has conceptualized the electro dialysis process.

Then in 1900 the word electro dialysis appears for the first time in 1911 Donnan exclusion theory was proposed in then after a huge gap up almost 40 years multi-component electro dialysis concept and the first synthetic ion exchange membranes were fabricated. Then in 1954 first ED plant bionics was established. Then in 1974 after a gap of almost 20 years EDR development by ionics, ionics is the company which is manufacturing the ED plants.

Then a 1987 first commercial use of BPM at Washington steel in Pennsylvania was reported then first ED production by Millipore also reported in 1987 then slowly, slowly electro dialysis proposed for zero liquid discharge, the first lab scale RED unit with captive electrodes. Shock ED proof of concept and all these things has come into picture and in 2015 recently coupling electro dialysis with wind photovoltaic and reverse electro dialysis system has been proposed.

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Now students let us understand what is reverse electro dialysis. So, we have discussed ED what is RED or reverse electro dialysis. So, it is a technology to generate electricity it is very important in the ED we are not generating electricity but here the concept is same but we can generate electricity from the salinity difference between the 2 solutions that is sea water and river water. Now what is being done is that you can see this particular there is a cathode there is a anode then

you are feeding your seawater here in this chamber one and chamber 2 and you are feeding fresh water that is river water.

If you take this is chamber 1 chamber 2 chamber 3 chamber 4 so in chamber 1 and 3 you are feeding your saltwater that means the feed is being feed or being transferred to the stacks in such a way that it goes between 1 cation exchange membrane and 1 anion exchange membrane and on the interspaces between 2 stacks so this is one stack this is another stack similarly this again another stake will go on.

So in the interspaces between these 2 electro dialysis texts so we will be feeding fresh water. So, this is fresh water. Now river water so what is happening is that so this system is composed of anion exchange membranes and compartments for sea and river water in alternating order. The ion exchange membranes have selected for either cations or anions the salinity difference between seawater on one side and river water on the other side of the membrane creates a potential difference.

So basically the potential difference is aroused because of the concentration of the ions in the seawater as well as river water or the salinity difference in the crude way you can tell that multiple cells each comprising a cation exchange membrane a seawater compartment and anion exchange membrane and a river water compartment can be piled up to increase the voltage. So, electrons at both ends of the pile facilitates a redox reaction which generates an electrical current to power an electric external device.

So RED is an electrochemical separation process that allows selective pressures of ions or charged species in solutions only anions or negatively charged ions can pass through ion exchange membrane and anion exchange membrane while cation exchange membrane transport positively charged ions. So, this is same this we have discussed at an earlier also. So, ion also transport through the ion exchange membrane by means of direct current voltage and that removed from feed water as the current drives the ion through the membrane to desalinate the process stream.

And the ED or the reverse electro dialysis system reduces the fouling tendencies of the water by reversing the polarity of the electrons in every 15 to 20 minutes. So, this is and get at advantage of the electro dialysis reverse electro dialysis system. The change in polarity causes the scale to dissociate from the membrane so that there is no scale formation that is going to happen on the surface of the membranes.

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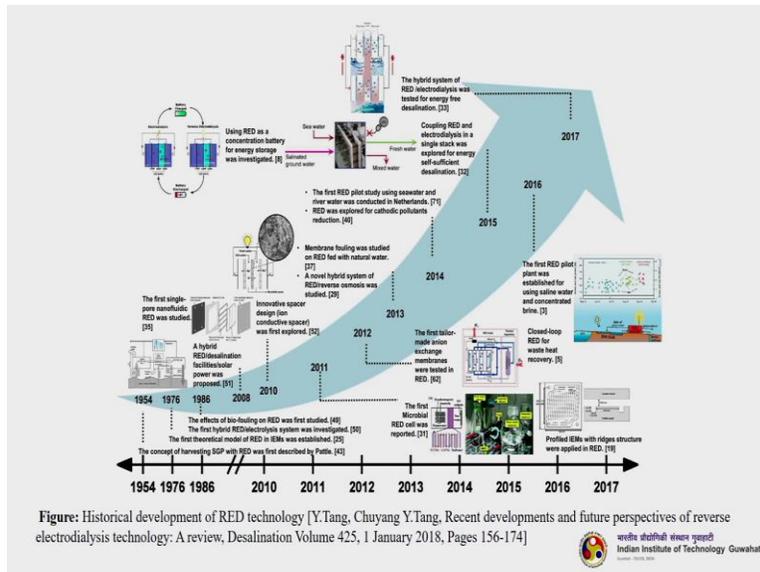
Reverse Electrodialysis

- The reverse electrodialysis process can successfully remove arsenic, radium, perchlorates as well as desalination of well and surface water.
- The application of reverse electrodialysis includes:
 - Municipal drinking water
 - Industrial process water, and
 - Wastewater reuse projects
- For wastewater reuse projects, the reverse electrodialysis process is ideal because of rugged membrane and high chlorine tolerance.



So the RED process can successfully remove arsenic, radium, perchlorate as well as desalination of well and surface water. The application are already includes municipal drinking water in the still process water and wastewater reuse projects. For wastewater reuse projects the reverse electro dialysis process is ideal because of the rugged membrane and high chlorine tolerance.

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So, this is another historical development of the RED technology you can see that it started from 1954 just after the first electrode ion exchange membrane was fabricated. Then 1976 the first theoretical model of RED in an exchange membrane was established the concept of harvesting SGP and RED was first described by Patel ok. So, then in 1986 a hybrid RED desalination facility solar power was proposed ok.

Then you can see there are so you can just go through it later on so then Micro Bell RED cell was reported in 2011 the first element anion exchange membrane were tested in RED that is in 2012 and the latest development is coupling RED in electro dialysis in a single stack was expert for energy self-sufficient desalination that means you know the RED; the ED is doing desalination the RED is producing energy.

But desalination we need some energy that energy will be replenished or will be supplied by the RED so that means one ED system and one RED system is being coupled together so that the RED will provide the energy that is required for the ED so that it becomes the self-sufficient desalination plant. And very recently now you can see that the RED plant was established for using selenium concentrated brine this is already this one.

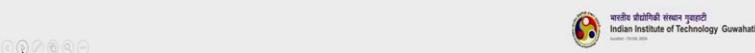
So, closed-loop RED for waste water recovery is also being proposed. Then you have profiled ion exchange membranes with ridges structure where applied in RED. Ridges of something like

this. so, anyway were not going into detail about this just the idea is to make you understand that how RED and how ED has developed gradually in successively.

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Text/References

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The slide contains a list of references under the heading 'Text/References'. At the bottom left, there are several small navigation icons (back, forward, search, etc.). At the bottom right, there is the logo of the Indian Institute of Technology Guwahati, which includes the text 'অসমীয়া শাস্ত্ৰীয় বিশ্ববিদ্যালয়' and 'Indian Institute of Technology Guwahati'.

So, with this I wind up most of the things are taken from different books like Kenneth and there are other books also. So, please go through the lecture and if you have any doubt please feel free to write to me at kmohanty@iitg.ac.in. So, in the next class we will be discussing one of the classic membrane separation process which is called pervaporation. So, it is basic principle advantages, membranes and modules how mass transfer is happening in pervaporations different pervaporation applications then hybrid distillation and pervaporation thank you very much.