Membrane Technology

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Lecture No 2
Membrane Processes and Classifications, Advantages,Disadvantages, Applications

Good morning students, today is the lecture 2 of module 1 in today's lecture we will discuss the classification of membrane processes and.

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Module	Module name	Lecture	Title of Lecture
01	Overview and membrane materials	02	Classification of membrane processes
			Various membrane processes, advantages and drawbacks
			Major applications

After that we will discuss one by one different membrane processes, basically I will give you a basic overview and understanding of different membrane processes. Then we will discuss about their advantages and drawbacks as well as some major applications of membrane processes in general.

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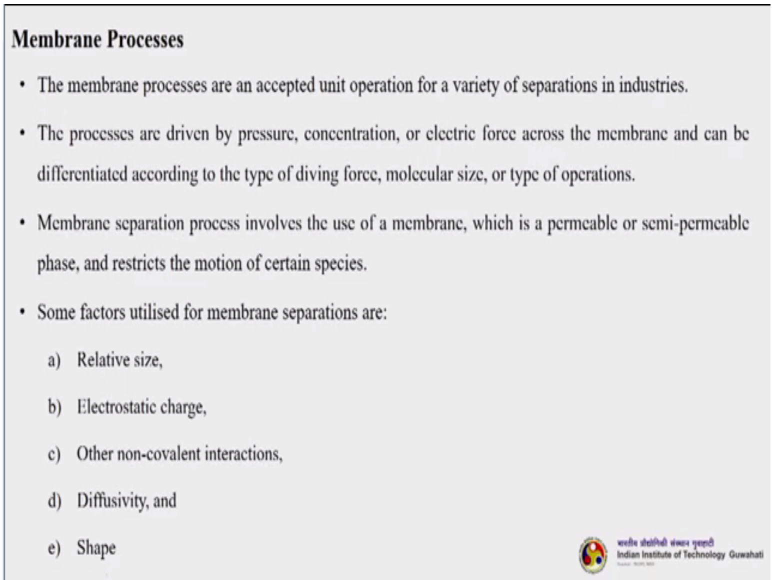

As you know membrane processes are an accepted unit operation, for a variety of separation in most of the industries whether it is a chemical or a veriety of industries. The processes are driven by pressure, concentration or electric force across the membrane. And can be differentiated according to the type of driving force, molecular size or type of operations now membrane separation process involves the use of a membrane.

Which is a permeable or semi permeable phase and restricts the motion of certain species. So we have understood what is the meaning of permeable or semi permeable in our last class so some of the factors utilized for membrane separation are relative size, electrostatic charge, other non-covalent interactions, diffusivity and shape.

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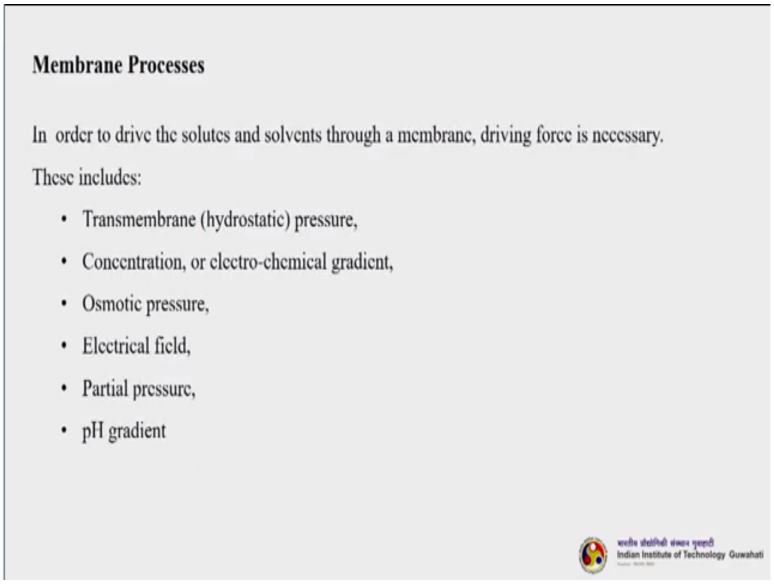

In order to drive the solutes and solvents through a membrane, driving force is necessary. If you remember students last class I told you that in the driving force is of various forms but the true driving force is always the difference in chemical potential. Since we cannot measure chemical potential directly hence we have to express the driving force in a measurable quantity or parameter which can be either transmembrane.

Or hydrostatic pressure concentration or electrochemical gradient it can be osmotic pressure gradient, it can be in the gradient of electric field, it can be partial pressure or it can be pH also. So as you can see all these parameters at different gradients and are readily measurable.

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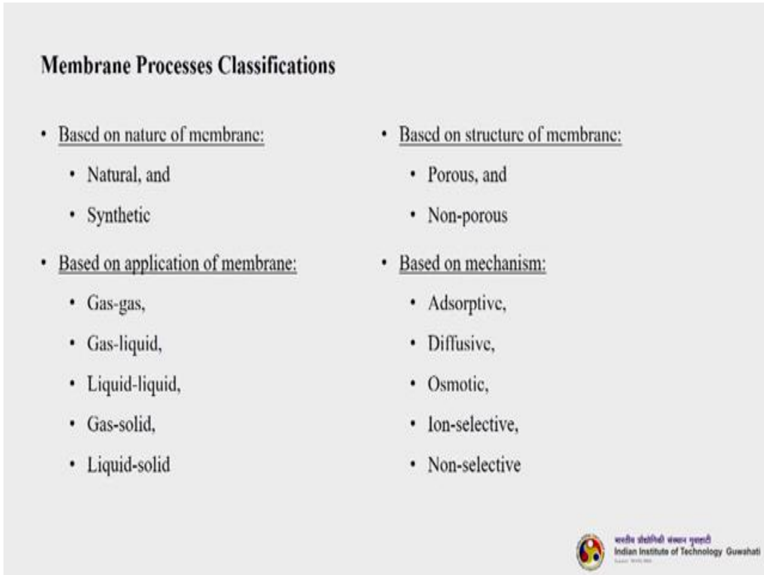

So, let us go to the membrane classification we can classify membranes into various types based upon the nature of membrane, based on application of a membrane, based on structure of membrane and based on mechanism. So according to this particular slide you can see that based on nature of the membrane it can be natural or synthetic based on application we can have gas gas, gas liquid, liquid liquid.

Based on structure we can have either porous on non porous membrane, the dense membrane or based on mechanism it can be either convective, adsoptive, diffusive or ion exchange.

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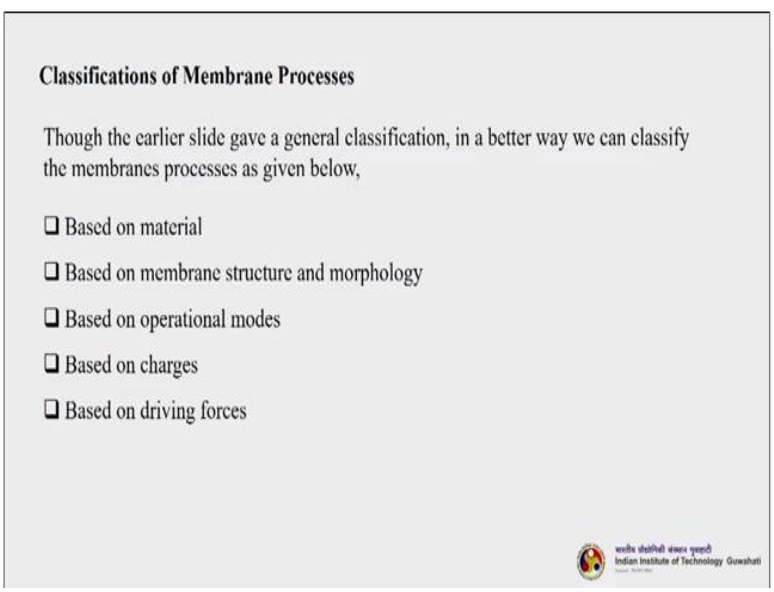

Now though the earlier slide gave a general classification in a better way we can classify the membrane processes as given below. So this I have tried to classify the membrane processes according to these five types, so first one is based on material, second one is based on membrane structure and morphology, third one is based on operational modes fourth one is based on charges and fifth on is based on driving forces. So we will see one by one so the first one is based on materials.

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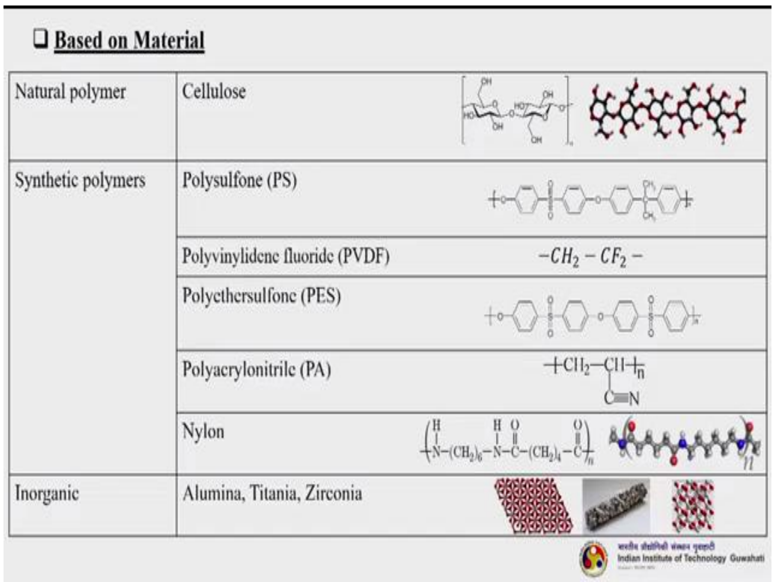

You can see that, either we can have a natural polymer which is cellulose is an classic example of a natural polymer cellulose is one of the most abundant early available natural material then otherwise we can have synthetic polymers. So most of the commercial membranes which you are available today in the market are all synthetic membranes, so it can be prepared either from poly sulfone or PVDF which is polyvinylidene fluoride or polyethersulfone.

Which is a modified version of poly sulfone or poly acrylonitrile or even nylon. So apart from this natural or synthetic polymers we can have inorganic membranes also which are usually called as ceramic membranes so these membranes can be prepared from various materials I have just listed three these are common materials either alumina, titania or zirconia.

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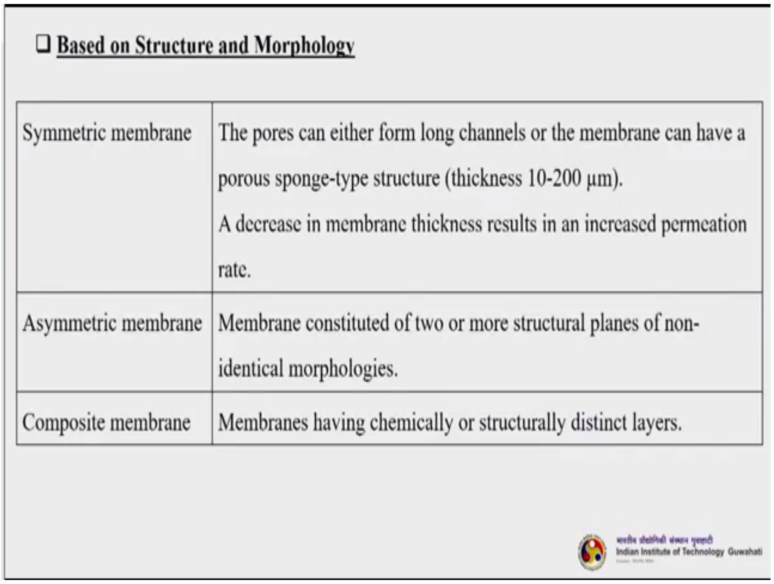

❑ **Based on Structure and Morphology**

Symmetric membrane	The pores can either form long channels or the membrane can have a porous sponge-type structure (thickness 10-200 μm). A decrease in membrane thickness results in an increased permeation rate.
Asymmetric membrane	Membrane constituted of two or more structural planes of non-identical morphologies.
Composite membrane	Membranes having chemically or structurally distinct layers.

So next classification is based on structure and morphology. So under this we can either have a symmetric membrane or asymmetric membrane or a composite membrane. A symmetric membrane is one, in which the pores can either form long channels or the membrane can have a porous sponge type structure usually the thickness is 10 to 200 mic and a decrease in membrane thickness results in an increased permeation rate.

The less the membrane the thickness, the less will be the resistance provided by this membrane so that the more will be the permeation and the more will be the flux also. So asymmetric membrane is one in which the membrane is constituted up to more structural plans of non-identical morphologies. So two different types of morphologies are fused together to give an asymmetric membrane.

And composite membrane is one which have chemically are structurally distinct layers, so nowadays we have usually the ceramic composite membranes in which ceramic part provides the porous or the best support, over which we can have a polymeric skin layer either in micro filtration or ultra filtration range to achieve a desired separation. So you can see how it looks like it basically though we have covered this

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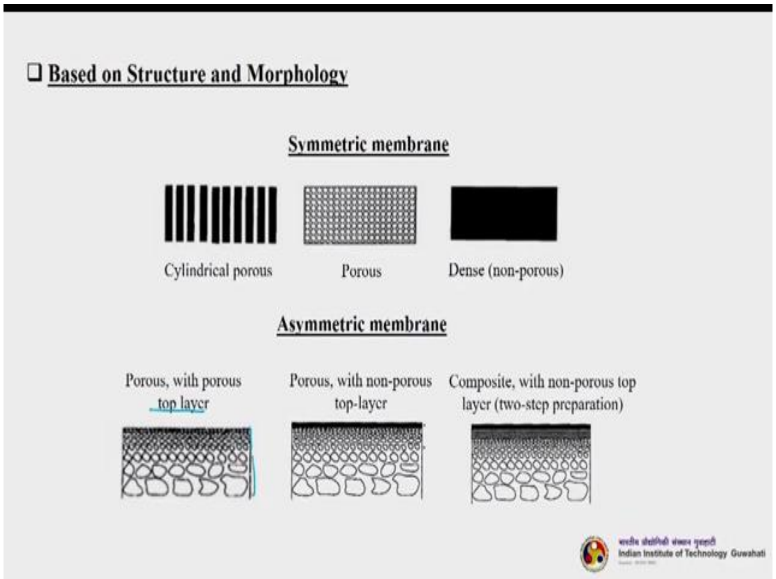

Little in our first class, so symmetric membrane either we can have cylindrical ports usually as I told you earlier also cylindrical pores are very difficult to achieve only the zeolite membranes have the cylindrical pores. So most of the membranes will have different types of pore sizes and shape and we can have a dense or non porous membrane also under the symmetric membrane we can have three different types of membrane.

The first is a porous membrane with a porous top layer, the first one you can see so we can have a porous membrane with a porous top layer and and this you can see the porous this is also porous, here the support is also porous. So another one we have a porous support here basically with a non porous top layer so this layer is actually a non porous layer. So this is another type of asymmetric membrane and the last one is a composite membrane.

And in which there is a top non porous membrane okay here this one and we can have a porous support here and intermediate also we can have another membrane with a little less porosity pore size than the below support one. So we can prepare it basically in a two step or three step preparation.

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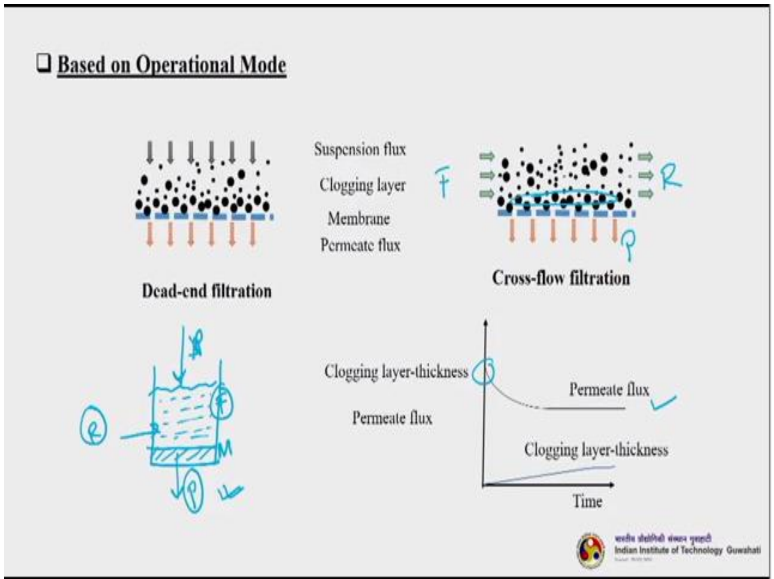

So the next one is based on operational mode so we can have a dead end filtration or we can have a cross-flow filtration. So mostly the membranes works in these two different modes so a dead-end filtration I just try to draw something so here you can see so let us say this is a cell in which I have put the membrane here, so this is my membrane okay and then we can fill in my mixture here which containing the solute which I want to separate.

And then I pressurize the system I applied pressure so I I will get permeate here so this is my Delta P that I am pressurizing this is my feed okay, and this is what I will get is permeate okay whatever is will be retained on the surface will be retentate. So this is a simplest form of our dead-end filtration and in which you can see the permeate flux declines just like here the permeate flux.

Initial permeate flux will be very high, and slowly slowly the permeate flux will decline flux decline. Flux decline will be more, in dead-end filtration more. So then the next one is the cross-flow filtration in cross-flow filtration the flow is you can see this is actually the feed is coming from here okay and it is passing over the membrane surface okay and we get retented here and we get permeate here.

So one of the best thing in cross flow system is there since the flow is perpendicular to our this one membrane surface okay, so the deposition whatever the deposition is happening here on the surface of the membrane which causes the concentration polarization will be little less than dead -end filtration more and of course flux decline profile will be same as in the case of dead-end filtration. However the flux a declining rate will be less than that of the dead end filtration.

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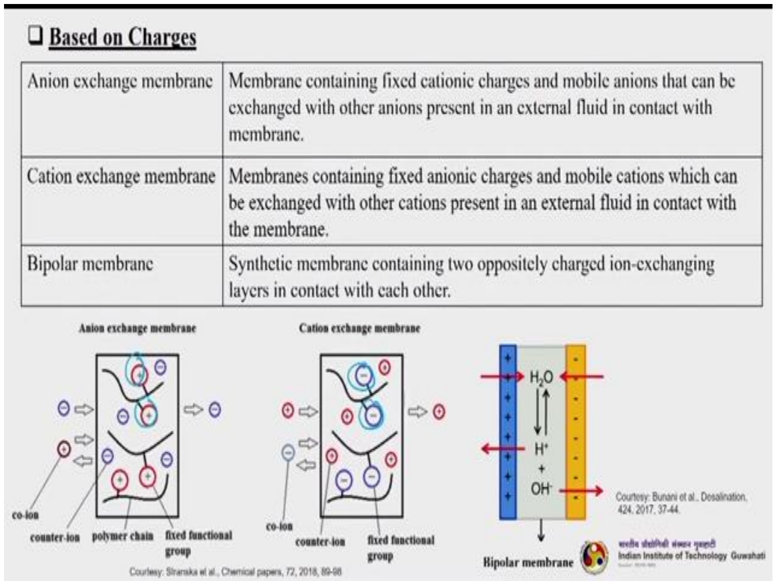

❑ **Based on Charges**

Anion exchange membrane	Membrane containing fixed cationic charges and mobile anions that can be exchanged with other anions present in an external fluid in contact with membrane.
Cation exchange membrane	Membranes containing fixed anionic charges and mobile cations which can be exchanged with other cations present in an external fluid in contact with the membrane.
Bipolar membrane	Synthetic membrane containing two oppositely charged ion-exchanging layers in contact with each other.

So the next one is based on charges, so we can have three different types of membranes here one is anion exchange membrane, another is cation exchange membrane and then the next one is bipolar membrane now, what is anion exchange membrane? So the membranes containing fixed cationic charges and mobile anions, that anions that can be exchanged with other anions present in an external fluid in contact with membrane.

So similarly in a cation exchange membrane the memberane we will be having fixed and anionic charges so please see this figure, in which you can see then in an anion exchange membrane we have fixed cationic charges. So these are the fixed cationic charges these are fixed inside a anion exchange membrane so anion exchange membrane basically means this membrane will have fixed cations.

And this membrane will exchange anions. Similarly in a cation exchange membrane we have fixed cations okay. And this will exchange the anions so cation exchange membrane is one in which cations will exchange with the help of fixed anions which are imported inside the membrane then we can have a bipolar bipolar membrane also so it is again a synthetic membrane containing two oppositely charged ion exchange layers in contact with each other.

So we can have a cationic layer and we can have an ionic layer fused together okay. That will do the separation for some specific purposes.

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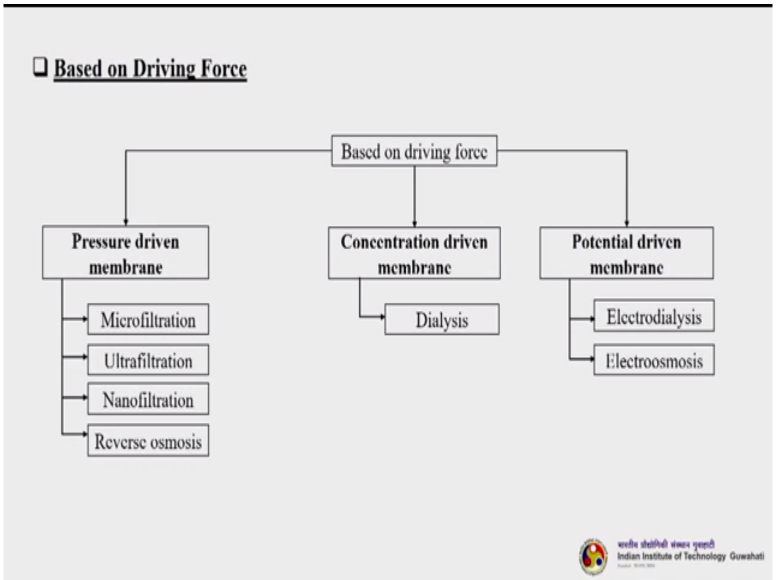

So the next one is based on driving force, so we can have three different types of classification under this particular sub classification. We can a pressure different and driven membrane under which the microfiltration, ultrafiltration and reverse osmosis nano filtration comes then we can have a concentration driven system or a membrane under which dialysis, hemodialysis comes.

Then we can have a potential driven membrane, which is electro dialysis and electro osmosis basically under the influence of electric gradient.

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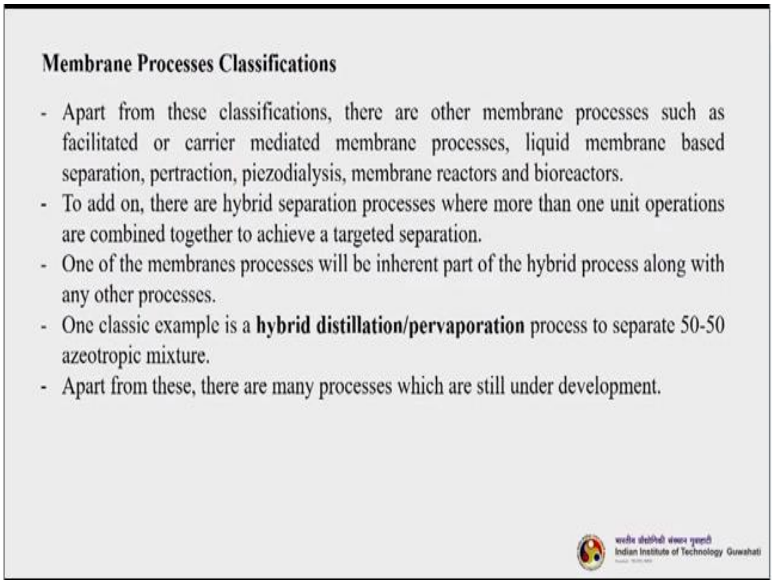

So membrane process, apart from these classifications we just tried to understand how membranes can be classified. Membrane processes can be classified into various sub classifications. So there are other membrane processes such as facilitated or carrier mediated membrane processes, liquid membrane based separation pertraction or pestraction also piezo dialysis membrane reactors and bio reactors.

And to add-on there are hybrid separation processes where more than one unit operations are combined together to achieve a targeted separation. And in a membrane hybrid system membrane is one part and part can be either distillation, absorption, adsorption or any other such unit operation, so one of the membrane processes will be the inherent part of the hybrid process. And there there can be any other processes which is joined together.

The joint with the membrane process to give us a particulate yield or separation. So one classic example of this hybrid process is the hybrid distillation and pervaporation process to separate a 50-50 isotropic mixture. So apart from this there are many processes which are still under development

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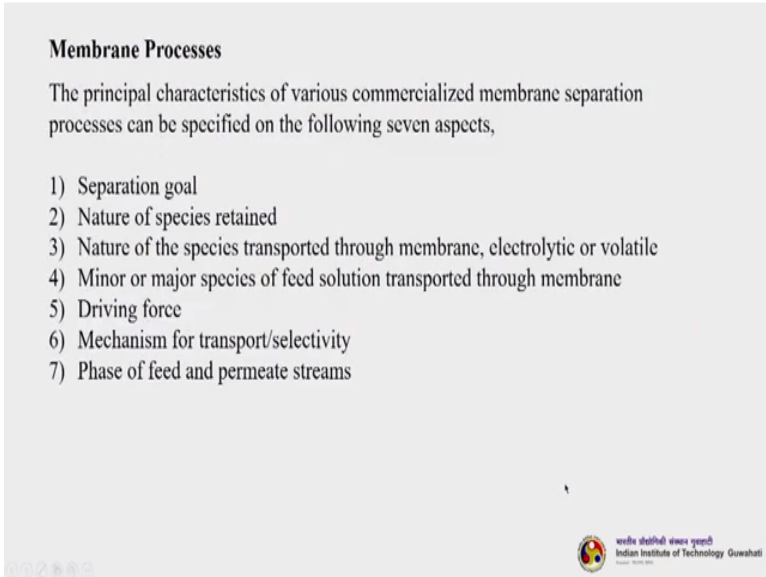

So the principal characteristics of various commercialized membrane separation processes can be specified on the following 7 aspects, these are very important. So these 7 aspects are separation goal, the nature of species retained, nature of the species transported through the membrane either electrolytic or volatile, minor or major species of feed solution transported through membrane, the driving force.

Mechanism of transport and selectivity. Phase of feed and permeate streams. So these are the seven principal characteristics for the commercial membrane separation.

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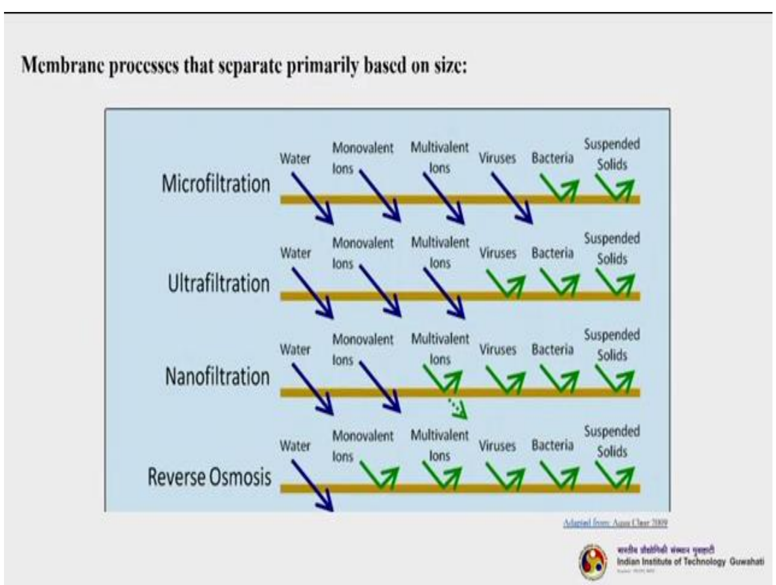

So let us now see if this slide will tell you, how the membranes which basically separate based on the size. So I have given the 4 basic membrane pressure driven membrane processes microfiltration ultrafiltration nanofiltration and reverse osmosis. Please have a close look to the slide you can see that in micro filtration water then different monovalent ions multivalent ions as well as viruses passed through.

That means the micro filtration membrane will allow all these to pass through the permeate side whereas it will retain bacteria and suspended solids. Then the ultrafiltration all these will will pass through however it will reject viruses, bacteria as well as suspended solids. In nano filtration again some of the monovalent are ions depending upon the sizes will be retained and some will pass through.

And it it will reject virus bacteria and suspended solids okay. And in reverse osmosis only whatever solvent can pass through all other ions viruses bacterias any suspended solid will be returned. So what we understand from this particular slide is there from, as we move from microfiltration, ultrafiltration then nano to reverse osmosis the pore size of the membranes decreases.

Since the pore size of the membrane decreases, it will be all these processes will lead need more Delta P that means the more transmembrane pressure is required so that it will separate it will give a desired separation.

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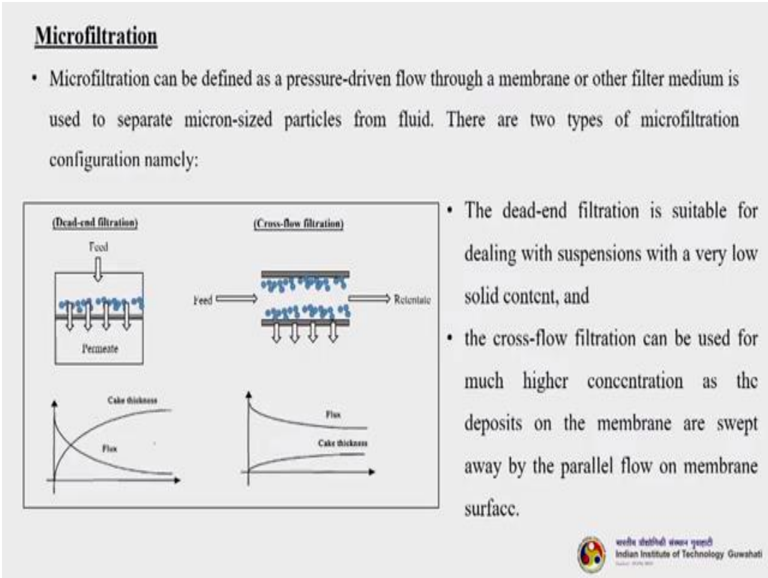

And now we will see one by one different membrane processes and I will try to give a brief introduction about that different types of membrane processes starting with microfiltration. So as you know that microfiltration can be defined as a pressure driven process where it is used to separate micron sized particles from fluid there are two types of micro filtration configuration namely one is dead-end and cross-flow filtration.

We just saw under the classification, when I show you the dead-end filtration mode and cross flow mode. And the dead-end filtration is suitable for dealing with suspensions with very low solid content. And please note that the dead-end filtration is not a commercialized industrial application this is used only in laboratory scale to characterize certain membranes and to develop a process.

There is no industrial applications of that, and the major application is of course the cross-flow filtration it is used for higher concentration as the deposits on the membrane are swept away by parallel flow on membrane surface.

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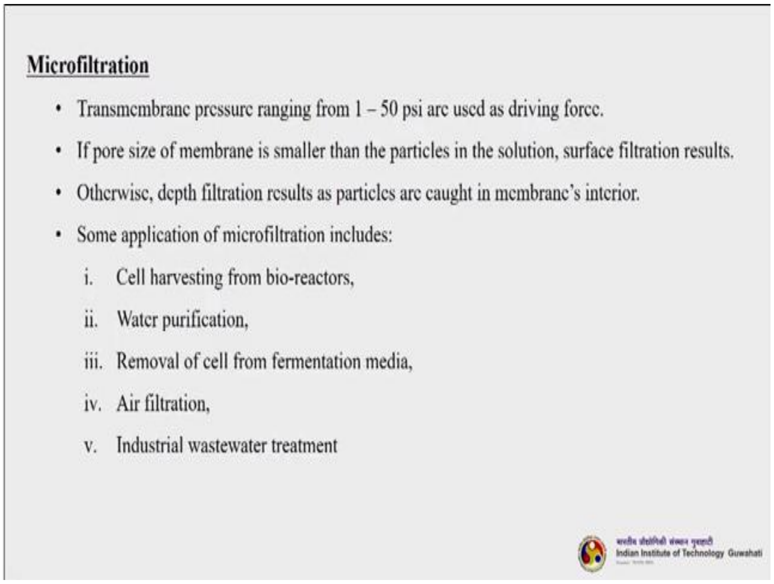

So a very highly concentrated solvents or mixtures can be processed through cross-flow filtration since the depositions are depositions of the solutes on the surface of the membrane are usually swept away by the parallel flow on the membrane surface. So transmembrane pressure ranging per micro filtration is usually 1 to 50 psi so that is the driving force. A pore size of the membrane is smaller than the particles in the solution.

Surface filtration will results, this means if the particles higher than the particle size is basically higher than the pore size of the membrane., then all of them will be retained on the surface of the membrane so the all of them will be rejected. Otherwise depth filtration results as particles are caught in membranes inter otherwise what will happen if the particle sizes have solute sizes are smaller than the membrane pore size.

So these particles or solutes will pass through the pores of the , so some of them will be passing through and then it will go through the permeate, some due to that various shapes and sizes of the pores will be retained, inside the membrane pores thereby creating internal fouling. So some application of micro filtration includes cell harvesting from bio-reactors when we culture various cells so bacterias,algaes or all these things.

So then it will be harvested once they are mature enough so micro filtration will help us in this in achieving this target, then water purification then removal of cell from fermentation media basically it is removal of dead cells then air filtration and industrial wastewater treatment

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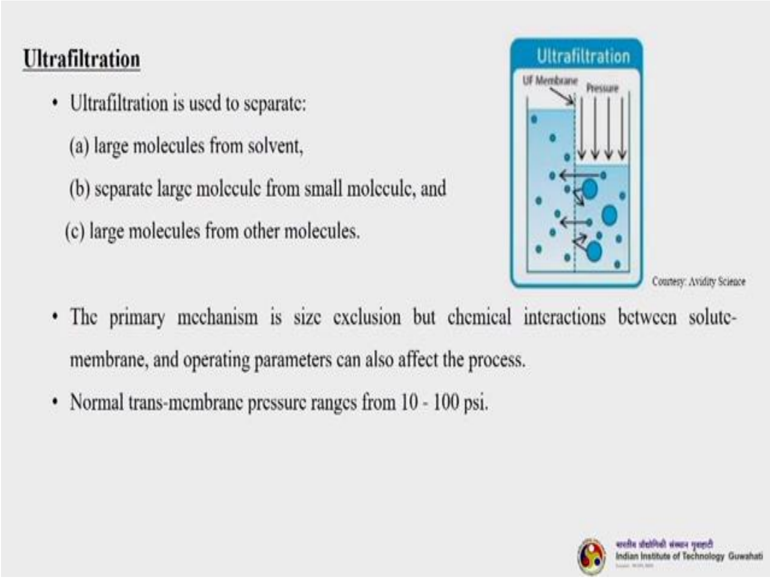

So next is ultrafiltration, so ultra filtration is used to separate large molecules of solvents the molecule size are usually larger than that of the micro filtration and separate large mole and separate large molecule from smaller molecule that basically it is, fractionation and large molecules from other molecules. So the primary mechanism is size exclusion just like our micro filtration.

But chemical interactions between solute and membrane and other operating parameters can also affect the process. So as I told you in the last class that one of the two very most important things which should be noted for any membrane separation process. First one is the physical chemical properties of the solute that I want to separate then the second one is the physical chemical properties of the membrane.

What the basically we can say the membrane material then normal transmembrane pressure for the ultra filtration ranges from 10 to 100 psi.

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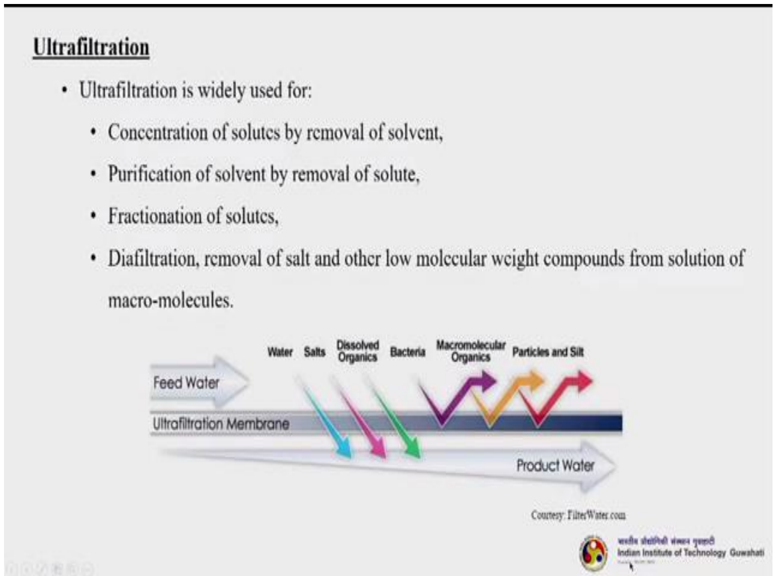
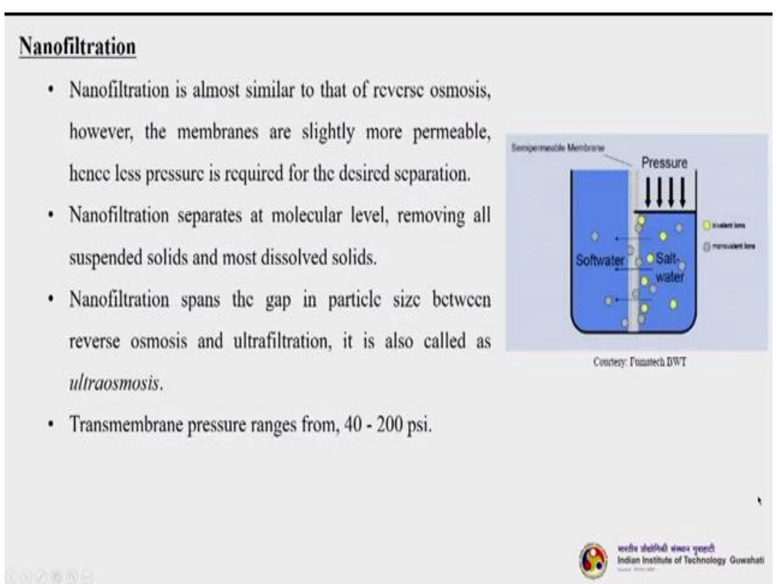


So ultra filtration is widely used for concentration of solutes by removal up by removing the solvent, purification of solvent by removal of solute, fractionation of solutes either binary fraction teritary or even more than that so you can have caskets also. Then diafiltration that is removal of salt and other low molecular weight compounds from solutions of macromolecules you can see this figure okay.

The ultra filtration membrane is allowing the passage of water, salts and dissolve organize whereas it is retaining the bacteria's macro molecular organics as well as particles and silts. **(Refer Slide Time: 18:51)**



Then we will discuss about nano filtration, so nano filtration is almost similar to that of reverse osmosis, however membranes are slightly more permeable. Since the membranes of nano filtration are little more permeable hence the pressure required for nano filtration is obviously lesser than that of the reverse osmosis and nano filtration separates at molecular level removing all suspended solids.

And most of the dissolved solids so nano filtration spans the gap in particle size between reverse osmosis and ultrafiltration. So basically nano filtration lies between somewhere between reverse osmosis and ultra filtration and that is why it is also called as ultra osmosis. So the transmembrane pressure from for this nano filtration usually range from 40 to 200 psi so the applications of nano filtration includes sea water desalination.

Then concentrate sugar and clarified sugar stream in sugar industry it has use application in sugar industries then a deacidification of whey, during the cheese production and recovery of dyes in textile industries, separation of heavy metals from water and waste water, removal of sulfate phosphate nitrate and fluoride. If you just look at the figure below you can see that nano filtration will allow.

Membrane will allow only water and salts to pass through whereas all other dissolved organics bacteria, viruses any other macro molecular organics and particles and silt will be retained or rejected by it.

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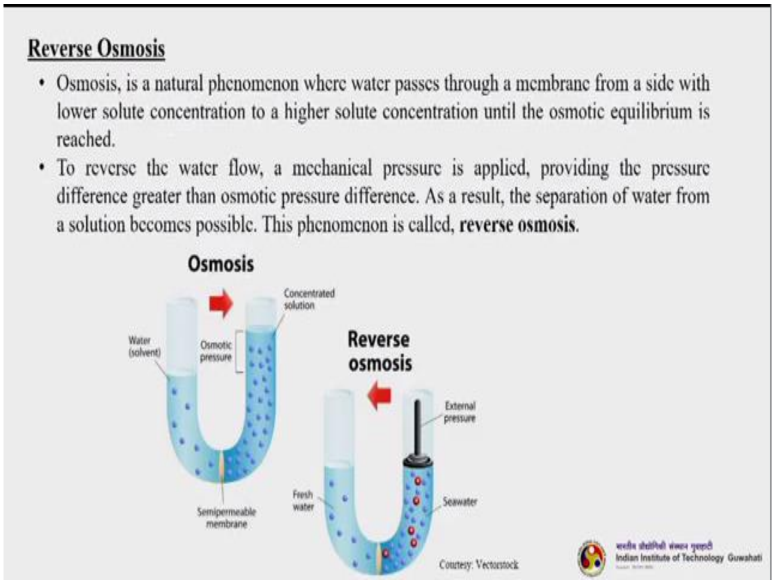

Then the next membrane process is called reverse osmosis so all of you all must have studied about osmosis during your school times, so osmosis is a natural phenomena see it occurs when the water passes through a membrane from a side with lower solute concentration to a higher solute concentration until the osmotic equilibrium is reached. So this is what is actually the water that is solvent is passing from here to here okay.

Using this is the membrane, so till osmotic equilibrium reached okay the flow will takes place so this is the osmotic pressure we can see from here okay, the concentrated solution side so and the membrane is of course a semipermeable membrane which will allow only the solvent or water to pass through and retain all sorts of ions. So to reverse the water flow to reverse this particular flow what is required is that we need to apply a pressure okay mechanical pressure okay.

Which should be which will overcome this osmotic pressure, whatever it is there okay the Delta Pi right so I apply external pressure here right, so this pressure will try to overcome this osmotic pressure okay so as a result the separation of water from a solution becomes possible okay this phenomenon is called reverse osmosis. So that means what we are doing we are acting against the gradient of natural chemical potential right?

So usually the flow should takes place from here to here, during osmosis since we want to remove solvent from the concentrated solution usually the application is desalination of seawater in which the seawater which is highly concentrated with salt has to be desalinated okay so in that case you will use reverse osmosis. We apply the pressure which will overcome that osmotic pressure so that air flow will starts from okay this side to this side.

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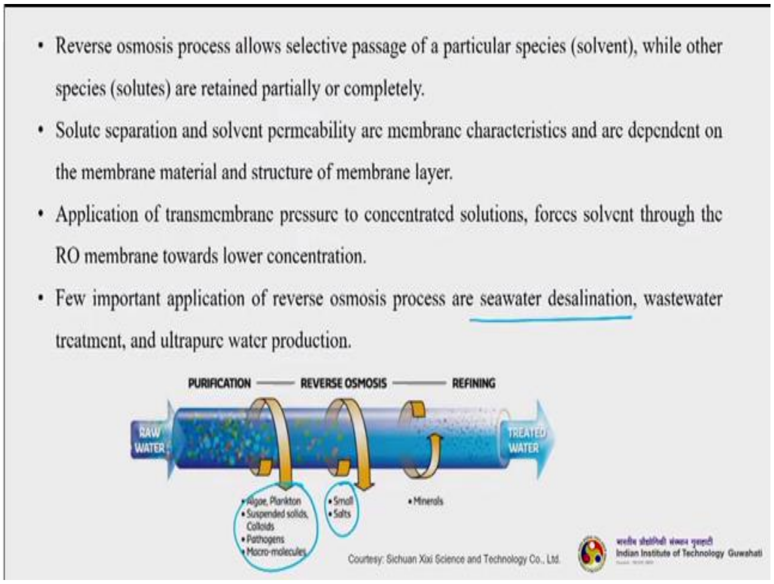

So reverse osmosis process allows selective pressures of a particular species usually the solvent while other species solutes are written or partially or completely. Solute separation and solvent permeability are membrane characteristics and that dependent on the membrane material and structure of the membrane layer. So application of transmembrane pressure to concentrated solutions forces solvent through the RO membrane towards the lower concentration.

So few important applications of reverse osmosis are sea water desalination, so which is the most important application of reverse osmosis then wastewater treatment even water treatment also and ultra, ultra pure water production. So you can see from the figure is that any all these things algae, plankton, suspended solids, pathogens, macromolecules, small molecule salts everything will be rejected by the RO membrane and only solvent will flow through the RO membrane okay.

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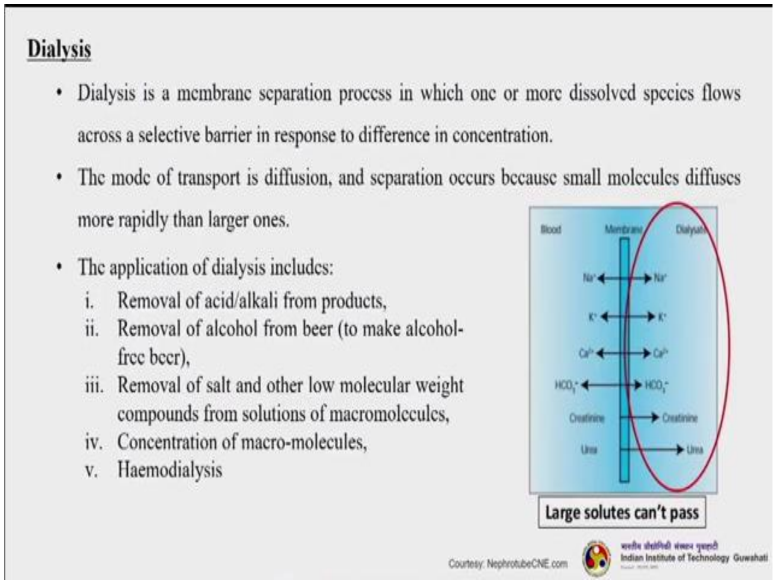

So the next process is dialysis so dialysis is a membrane separation process in which one or more dissolved species flows across a selective barrier in response to a difference in concentration, so please remember that dialysis is a concentration driven membrane separation process. so the mode of transport is usually diffusion, and the separation occurs because small molecules diffuses more rapidly than larger ones.

So it is quite understood than smaller molecules diffusivity will be higher than that the larger molecules so the rate of diffusion plays a very important role, in separating of these molecules. So you can see this particular figure you can see that through this membrane through our this dialysis membrane sodium potassium calcium can pass through okay whereas creatinine and urea.

Which are large molecular components will be rejected by the dialysis membrane. So this is what is the application of basically hemodialysis is where the blood is purified. So the application of dialysis includes the removal of acid and alkali from products removal of alcohol from beer nowadays there is a lot of demand of making alcohol free beer in Western countries so that is why alcohol will be removed from the beer using this dialysis membranes.

Removal of salt and other low molecular weight compounds from solution of macromolecules then concentration of macromolecules as well as hemodialysis. So one of the most prevalent application of dialysis is the hemodialysis.

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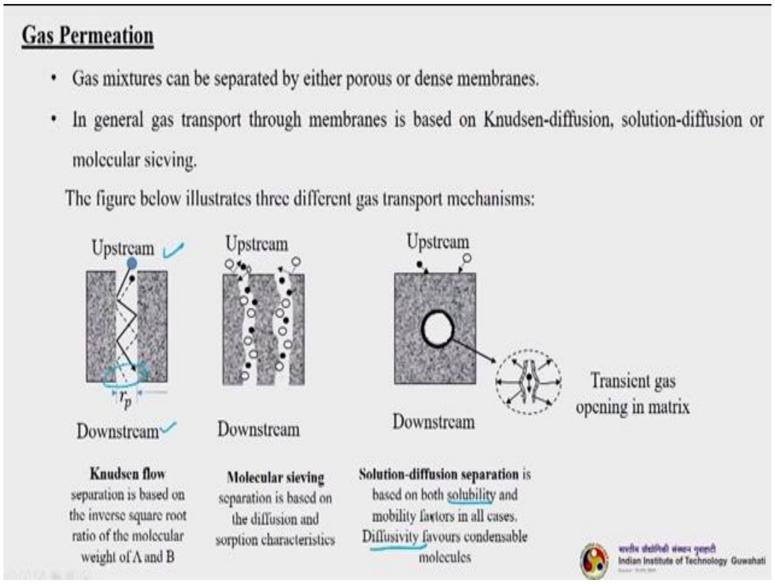

So the next application is gas permeation, so gas permeation or gas separation is one of the most important application of membrane separations and it has lot many industrial applications. So gas mixtures can be separated by either porous or dense membranes we can use both porous and non porous membranes, so in general the transport through membrane is based on knudsen diffusion, solution diffusion or molecular sieving.

So I have just tried to show you three different types of mechanism through which the gas separation takes place you can see this is the membrane okay and this is the upstream side and this is the downstream side of the membrane. In three cases the first one is not sent flow so here the separation is based on the inverse square root of ratio of the molecular weight of a and B if I am separating both a and B okay.

So RP is the diameter of the port this is one pore and RP is the diameter of the pore so the separation is happening due to knudsen diffusion. The next one is molecular sieving in which the separation is based on diffusion and certain characteristics right? So the rate of diffusivity of the solutes plays a important role in this type of separation the next one is solution diffusion separation.

As you understand the name solution diffusion so the separation is based on both the solubility as well as diffusivity of the solute for the separation okay so gas separationhas a lot many applications.

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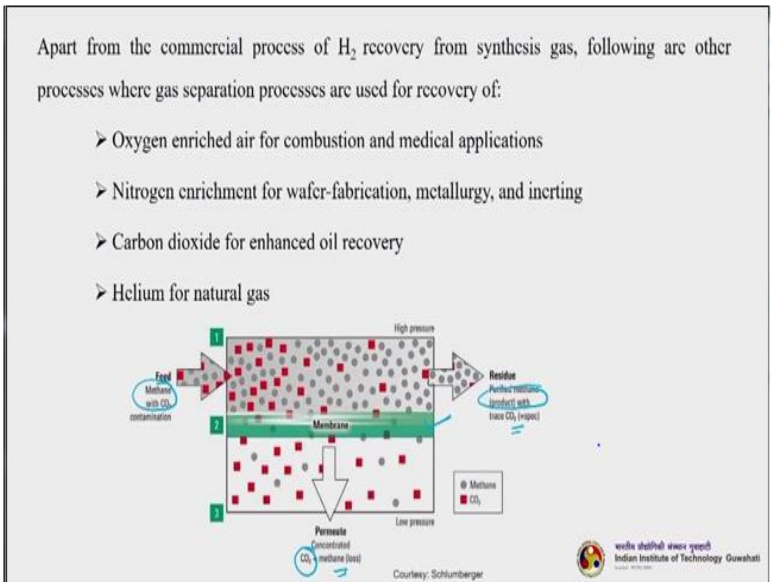

So, the one of the most important commercial application is the hydrogen recovery from synthesis gas okay. And then oxygen enriched they are for combustion and medical applications. Nitrogen enrichment for wafer-fabrication metallurgy and other applications carbon dioxide for enhanced oil recovery, minimal up carbon dioxide then helium for natural gas. Now you can see this particular application in which we are trying to remove carbon dioxide from a mixture of methane and carbon dioxide.

So the feed contents both methane and carbon dioxide and I use a gas separation a membrane or we can, I can call it as a carbon dioxide selective membrane, in which the carbon dioxide will be selectively separated or permeateted through. So we get more carbon dioxide heats here and we will get purified with on here so of course due to the porous on inherent nature of the membrane some methane will come to the membrane side.

Similarly for carbon dioxide which is very tres will return will also go through the methane but we will get, we are having a nowadays we have excellent carbon dioxide selective membranes. So which will select which will permeate carbon dioxide almost up to 95 98 percent or even more than 99 percent also. So another application is little this one extended application of gas absorption is gas absorption and stripping so unlike the conventional membrane process.

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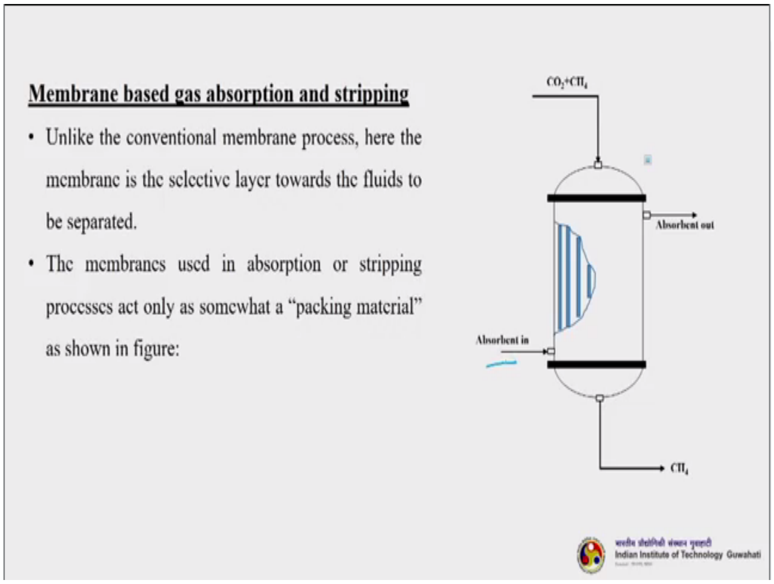

Here the membrane is the Selective barrier or selective layer towards the fluids to be separated, the membrane used in absorption or stripping processes act only as somewhat a picking material as shown in the figure. So you can see this instead of having a peg bed for doing the adsorption we can have membranes okay pegged as a packing material. So we can have the absorbent in here okay an absorbent out here.

So the same application of the carbon dioxide and methane which is present as the feed okay will be used here okay, to separate or to get purified methane so carbon dioxide will come out here.

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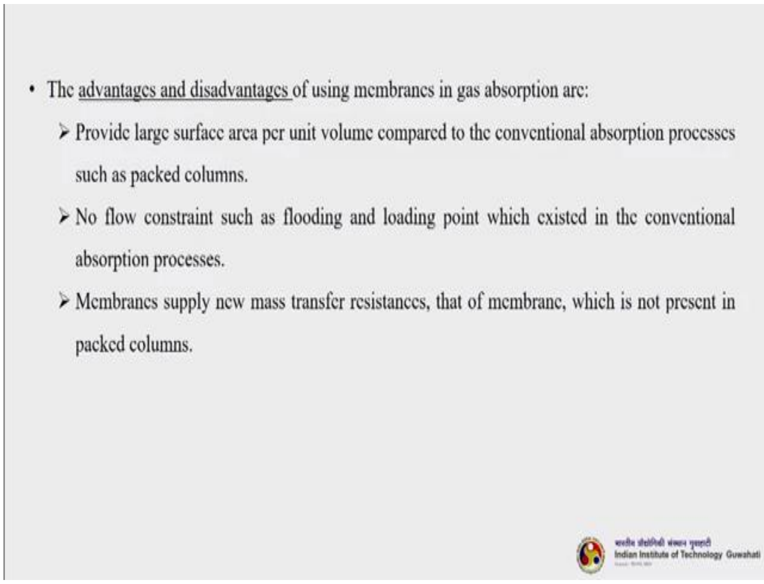

So the advantages and disadvantages of using membranes in gas absorption are, it provides large surface area per unit volume okay that is very important because to have a better mass transfer we should have more surface area. So in a smaller place we can have more surface area by providing this type of membranes, with reference to of course the conventional absorption system. And no flow constants such as floating or loading existence as those existing and usual to conventional absorption processes and membranes supply.

New mass transfer resistances that of the membrane which is not present in the packed columns. so this is one of the disadvantages of having membranes as a packing materials so the membrane thickness will provide a resistance to mass transfer however, if we can have a very thinner membrane then we can almost nullify their resistance to flow which is being provided by the thickness of the membrane. The next is pervaporation, one of the most.

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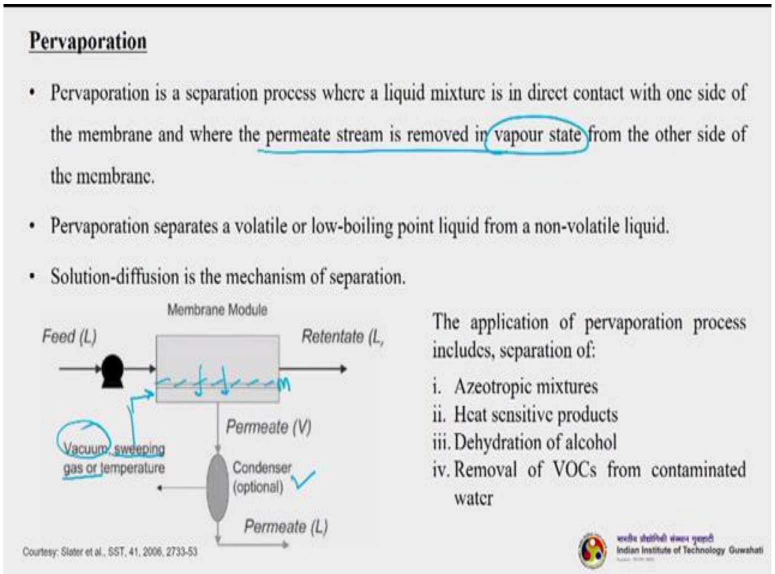

Important application in membrane separation, so it is a process where a liquid mixture is in direct contact with one side of the membrane and where the permeate stream is removed in vapor state. So this is very important the permeate is getting removed in a vapor state, okay from the other side of the membrane. So for the pervaporation the name comes actually from the from what I said just before that it is permeate vaporization.

The permeate is getting vaporized, so pervaporation separates usually a low volatile or low boiling point liquid from a non volatile liquid. And solution diffusion is the mechanism of the separation please have a look at this figure you can see the feed is entering here here this is the this is your membrane right and what is happening the feed is liquid and whatever retentate I am getting that is also a liquid right?

The permeate when it is passing through the membrane here okay is getting vaporized, so I can achieve the vaporization of the permeate by two processes either I can have a vacuum pump here which will create the preparation of the permeate here, so thereby creating basically it will create a low vapor pressure there. And otherwise I can have a sweeping gas so I either I can have a sweeping gas somewhere here.

I can pass a sweeping gas so that it will pass through the so it will create a low vapor pressure okay and the condenser is optional if I wind up this one permeate as a liquid phase then we can have a condenser so that major replications of pervaporation are the breaking of azeotropic mixtures or the separation of azeotropic mixtures, as you know that usually the azeotropic mixtures can be separated by a zeotropic distillation.

Or we can go extractive distillation, where we are adding a third solvent and that by increasing the cost of the entire process then we can help the heat sensitive product separation using pervaporation, dehydration of alcohol is a classic example and it is commercialized process also and then removal of VOCs volatile organic compounds from contaminated water. So these are some of the classic examples of membrane pervaporation process.

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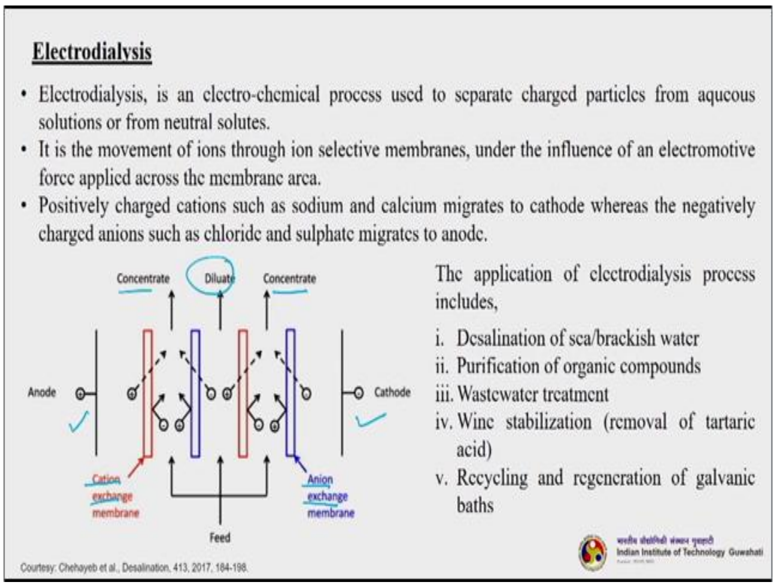

So the next process that will discuss is electro dialysis. So it is a dialysis process which is happening under a electric gradient, so electro dialysis is an electrochemical process used to separate charged particles from aqueous solutions or from neutral solutes. So it is the movement of ions through ion selective membranes under the influence of an electro-motive force applied across the membrane area.

So positively charged cations such as sodium and calcium migrates to the cathode whereas negatively charged anions such as chloride and sulfates migrate to the anode. So please see this particular figure of the schematic here you can see there is a anode here there is a cathode here and we have here in this particular figure, we can see four different types of membrane so the red one is cation exchange membranes.

And the violet color one is the anion exchange membrane, so a cationic as we understood previously in this lecture only the cation exchange membrane will have fixed anions and anion exchange membranes will have fixed cations. So feed is passed from the below I can pass the feed from the top also then I got diluate from here and concentrate from here so the applications of electrodialysis process are desalination of sea and brackish water.

This is one of the most important applications so where desalination can be achieved by electro dialysis as well as e-beam by reverse osmosis or nano filtration also. So purification of organic compounds wastewater treatment wine stabilization, where we remove actually the tartaric acid which is forming when the fermentation is happening and then recycling and regeneration of galvanic baths in the metallurgical industries actually.

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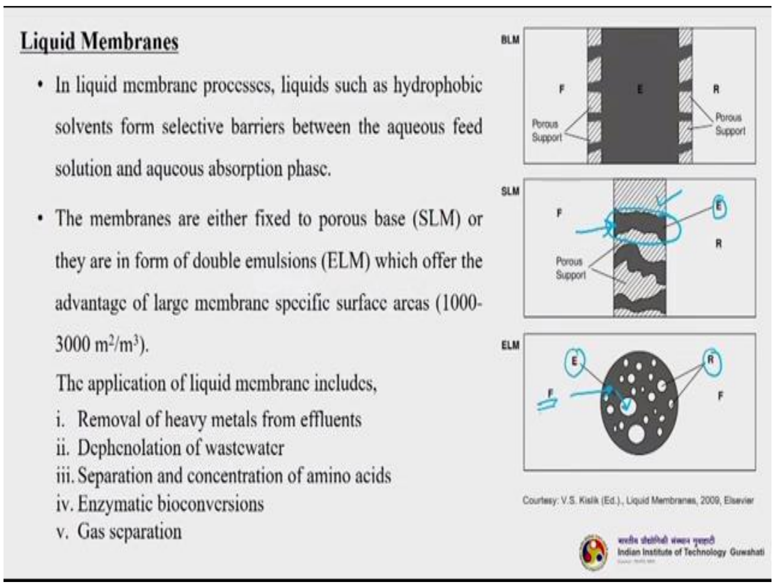

So the next process is actually liquid membranes. Students I told you in the next class how what is actually basically is a liquid membrane a liquid membrane is essentially the membrane is made up of a liquid so here the liquid such as hydrophobic solvents form selective barriers between aqeous feed solution and aqeous absorbtion phase. So please see, a look at the figure so we can have three different types of liquid membranes BLM SLM and ELM.

So the BLM stands for the bulk liquid membrane, SLM stands for the supported liquid membrane and ELM stands for the emulsion liquid membrane. So bulk liquid membranes are not commercialized they are utilized in the lab scale to generate data and to see whether the process of liquid membrane is feasible for a particular separation or not and in SL m SL m and e l ms are the already adapted in various industrial sectors.

So SL m is a supported liquid membrane where there is a support, so this you can see this is a membrane so this can be a micro porous membrane where micro filtration membrane and what we are doing is basically we are putting the membrane phase which is present in the pores inside the pores so this is a particular pore, so you can see that the membrane which is a liquid is impregnated inside the pores of the membranes.

So the separation will be achieved here only brain itself is not doing anything it is just providing the mechanical support or it is just holding the liquid membrane phase. Similarly in the case of emulsions membrane, so the membrane phase you can see that this is the membrane phase E is the membrane phase this is the feed phase okay. R is the receiving phase okay so the membrane phase is we will do the separation of the solutes from the feed.

So the separation will happen like this then eventually it the solute will go to the receiving phase and will get inside the receiving phase then we can have emulsifier breaker breakers which will break the emulsifier we will get the solute so you want to separate from the feed stream that will go to the receiving place and then we can recycle the membrane phase again the major advantage actually of the ELM is that we can create very high membranes specific surface area, almost 1000-3000 meters square per meter cube okay, In. a very small space okay

The application of liquid membrane includes removal of heavy metals from effluents, deep finalization of waste water that means removing phenol from various water system water in wastewater systems bodies and then separation and concentration of amino acids and geometric bio conversions and gas separation.

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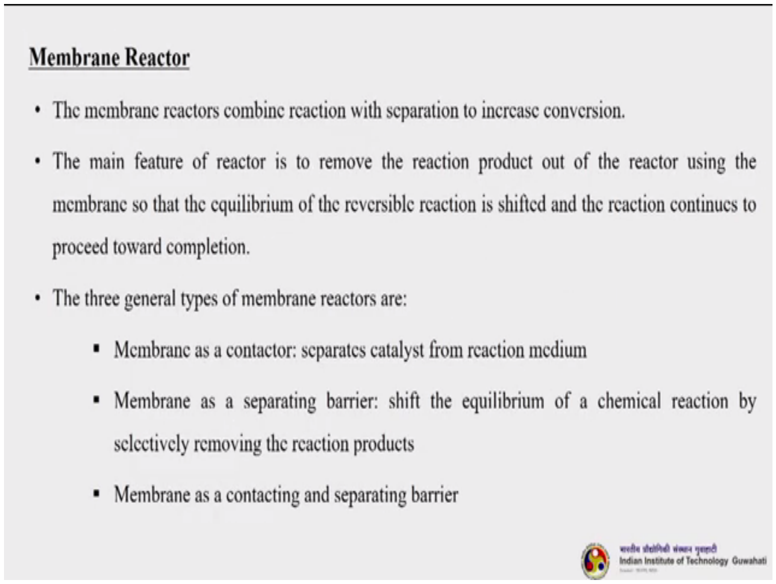

So the next membrane method is membrane reactors we will just go through a little basics of what is membrane reactors, later on we will discuss in one of our lecture in detail about membrane reactors and bio reactors. So the membrane reactors combined reaction with separation to increase conversion the main feature of the reactor is to remove the reaction product out of the reactor using the membrane.

So that the equilibrium of the reversible reaction is shifted and the reaction continues to proceed toward completion. So I am continuously removing one of the reaction product which is not a valuated product for me so that the main product yield will be higher than that of the bi product. So the three general types of membrane reactors are possible one so the first one is membrane act as a contactor so basically here in this type of system.

The job of the membrane is to separate catalysts from the reaction medium, a catalyst from the solid catalyst the heterogeneous catalyst then a membrane as a separating membrane act as a separating barrier here the job of the membrane is to shift the equilibrium of a chemical reaction by selectively removing the reaction products, one of the reaction products are a bit more than one of the reaction products.

And another one configuration membrane act is both a contacting and separating barrier

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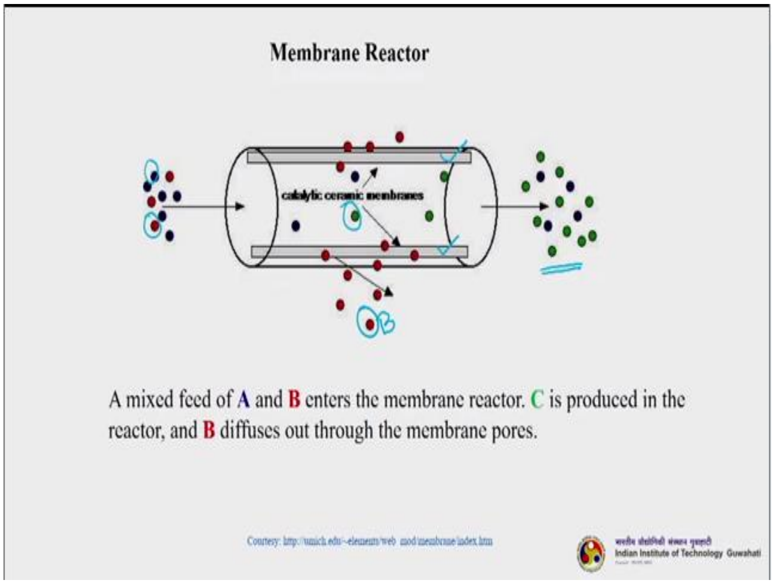

So let us see this figure here you can see there is a mixture of A and B. So this is A and this the red one is B so both are passing or entering through the membrane reactor and inside the membrane reactor catalytic conversion takes place so we can see two ceramic membranes here tubular ceramic membranes here, there can be many more just for our understanding we have seen two I have shown two here.

So C is the product which is forming inside the membrane reactor and then it is coming out here, so we are getting the product here. And what that these membrane reactors are doing they are selectively removing the B this is B they are selectively removing the B, so that the yield of C will be more so C is produced in the reactor and B is diffusing through the membrane pores so be selectively removed.

So that there will be no B present here here in the product and you will have the product which is C will be more

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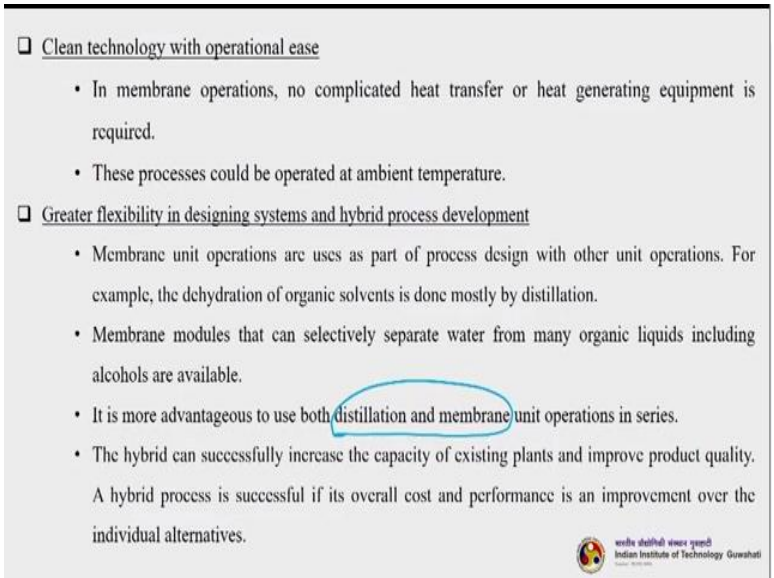

And now let us see the different advantages and disadvantages of the various membrane processes. so the first and foremost important advantage of the membrane processes appreciable energy savings. I told you in the last class also in a nutshell but let us see what is the meaning of that actually compared to conventional processes membrane separation technology permeates concentration separation without the use of heat.

In all other conventional processes we need heat to do either concentration or separation here we don't need so there is a lot of energy saving here. So evaporation and freeze concentration are common dewatering techniques used for liquid products, evaporator requires input up almost 100 BTU per pound. While freezing requires 144 BTU per pound to change the state of water from liquid to vapor and liquid to solid respectively.

Since membrane processes do not require a change in the state of the solvents so that do not require a change in the state of the solvent except maybe pervaporation so to effect dewatering it resulted in considerable saving in energy. Then clean technology with operational ease so the membrane operations no complicated heat transfer or heat generating equipment is required these processes could be operated and ambient temperature.

So the next one is greater flexibility in designing systems and hybrid process development as I told you earlier also one of the best advantage of membrane process is that it can be hybridized along with any other unit of presence such as distillation absorption adsorption and any other such operations so membrane unit of presence are uses as part of the process design with other of unit operations for example dehydration of organic solvents is done mostly by distillation.

Membrane modules that can selectively separate water from many organic liquids including alcohols are available it is more advantageous to use both distillation and membrane unit operations in series.

So if you do a combination of distillation and membrane okay a hybrid system then we can save appreciable energy and even space also, the hybrid system can successfully increase the capacity of existing plants and improve the product quality a hybrid process is successful if its overall cost and performance is an improvement about the individual alternatives otherwise why should we go for a hybrid system.

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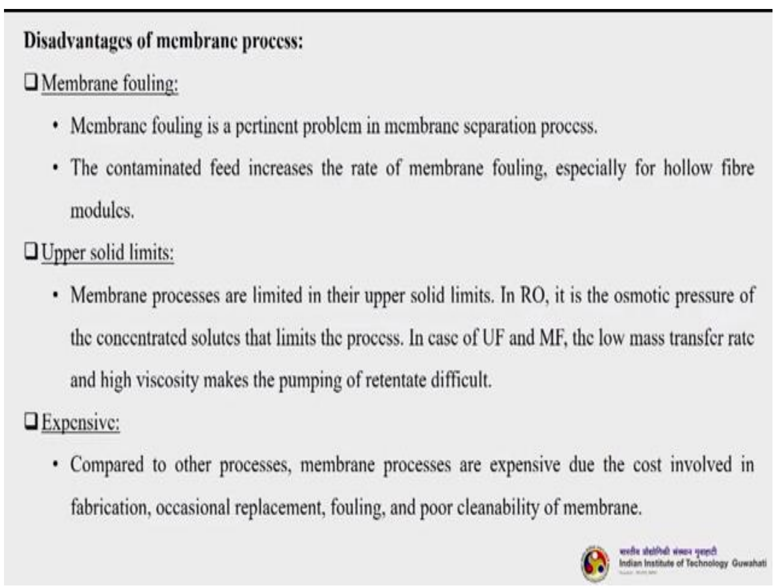

So next is disadvantages of membrane systems, so we have we understood what are the advantages it is not always that membrane is we knew in situation for any propellant separation need there are certain disadvantages the first one is membrane fouling so membrane fouling is the pertinent problem in membrane separation process the contaminated feed increases the rate of membrane fouling especially for hollow fiber modules.

So as you understand the last class actually we discussed how fouling taking place so fouling is a consequence of concentration polarization. So concentration polarization is the deposition of solutes about the membrane surface which happens gradually, so when excess deposition happens some of this solutes will passed through the, will try to squeeze themselves and get inside the pores of the membrane.

Thereby blocking the pores mouth as well as pours the constricted passage of the pore inside the membrane so thereby doing two types of fouling either external fouling or internal fouling. Then the next one is upper solid limits so membrane processes are limited in their upper solid limits so what is the meaning of this thing in RO, reverse osmosis it is the osmotic pressure of the concentrated solutes that limits the process okay.

So you have to in RO you have to just cross the barrier of the osmotic pressure then only by providing a mechanical pressure excess then that of the osmotic pressure, so that the separation will happen. So in case of ultra filtration and micro filtration the low mass transfer rate and high viscosity makes the pumping of the retentate difficult, so if you are having a very highly viscous so solvent.

Which is our retentate then taking it out so basically pumping it out from the membrane module on the membrane reactor system becomes between bit difficult and challenging then the next one is expensive so compared to other processes membrane processes are expensive due to the cost involvement in fabrication, occasional replacement, fouling and poor clean ability of the membrane.

But nowadays with huge advancement in membrane Science and Technology the cost of the commercial membranes have come down drastically.

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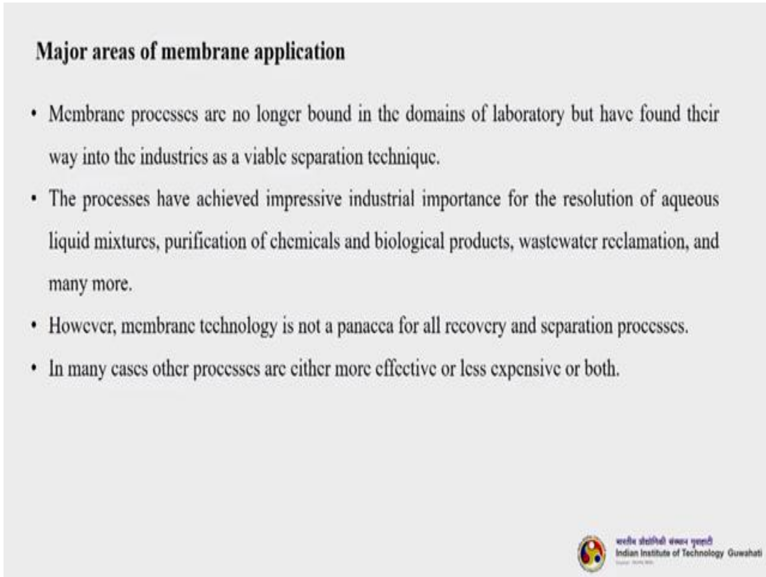

So the major areas of membrane applications so let us see a few areas and we will try to understand how membrane plays a role in few of the industrial applications so membrane processes are no longer bound in the dominance of the laboratory, but I found in extensive applications in various industries so the processes have achieved impressive industrial importance for the resolution of aqueous liquid mixtures.

Purification of chemicals and biological products, wastewater reclamation and many more many more such applications, however membrane technology is not a panacea for all recovery and separation process in many cases the other processes either more effective or less expensive or it can be both.

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Major areas of membrane application

Industrial sector	Membrane processes
Drinking water	RO, NF, UF
Demineralised water	RO, ED, EDI
Wastewater treatment	
Direct (physical)	MF, NF, RO, ED
Membrane bioreactor	MF, UF
Food industry	
Dairy	UF, RO, ED
Meat	UF, RO
Fruits and vegetables	RO
Drain milling	UF
Sugar	UF, RO, MF, NF, ED

So you can see the different industrial sectors and the applications so in the drinking water we can use either ultrafiltration nanofiltration reverse osmosis. In demineralization of water we can use RO, electro dialysis and wastewater treatment whether it is direct physical treatment or membrane bioreactor we can use all sorts of membrane pressure different membrane processes as well as electrical driven membrane processes such as micro filtration.

Ultrafiltration, nanofiltration reverse osmosis, electro dialysis and in food industry we have a major application in food industry the membrane application whether it is dairy industries meat industries, fruits vegetable processing industry, sugar industry we have used ultra filtration RO and ED membranes electro dialysis systems to do the separation

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Major areas of membrane application

Industrial sector	Membrane processes
Beverage industry	
Fruit and vegetable juice	MF, UF, RO
Wine and breweries	MF, UF, RO, PV
Tea and coffee	MF, UF, NF
Biotechnology	
Control release	UF
Haemodialysis	UF
Concentration of fermentation broth	MF
SCP harvesting	UF, MF

In beverages industry like fruits and vegetable juices wine and breweries tea and coffee industry also use microfiltration, ultrafiltration, RO and pervaoration membranes in biotechnology industries the applications of ultra filtration and micro filtration is more prevalent than any other membrane processes.

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Major areas of membrane application

Industrial sector	Membrane processes
Chemical industry	
• Gas separation	
Hydrogen recovery	GS
Carbon dioxide separation	GS
• Vapour liquid separation	
Ethanol dehydration	PV
Organic recovery	PV
• Hydrometallurgical processing	UF
• Energy	
Fuel cell	Proton exchange membrane

So in chemical industries, basically that gas separation where whether it is we talk about the hydrogen recovery, carbon dioxide separation and nitrogen enrichment we use the gas separation membrane specific gas separation membranes to do the separation and when we go for a vapor liquid separation just like our for example enthanol dehydration or organic recovery so you use the pervaporation membranes.

So in case of fuel cells we use proton exchange membranes which PM. which is called PM. fuel cells okay. So in chemical industries.

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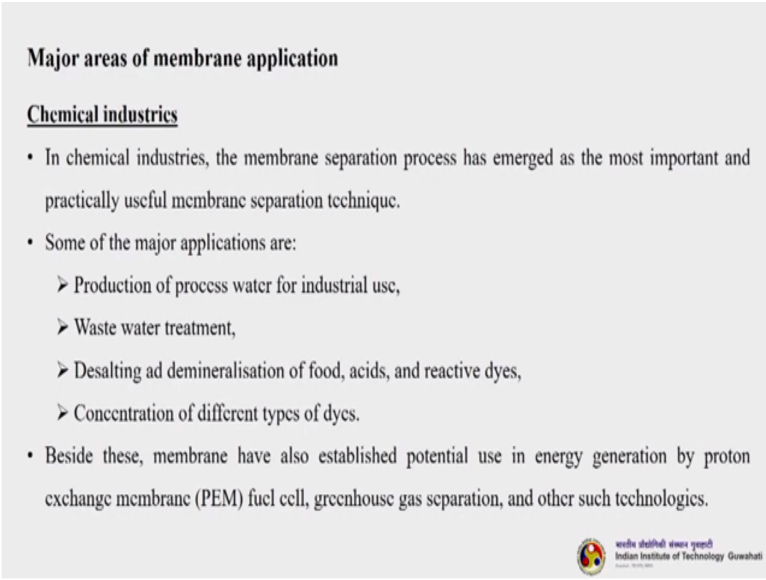

The membrane separation process has emerges the most important and practically useful membrane separation technique so some of the major applications are production of process water for industrial use, wastewater treatment desalting and demonization of food acids and reactive dyes concentration of different types of dyes so besides these membranes have also established.

Potential use in energy generation by proton exchange membrane fuel cell green house gas separation and other such technologies.

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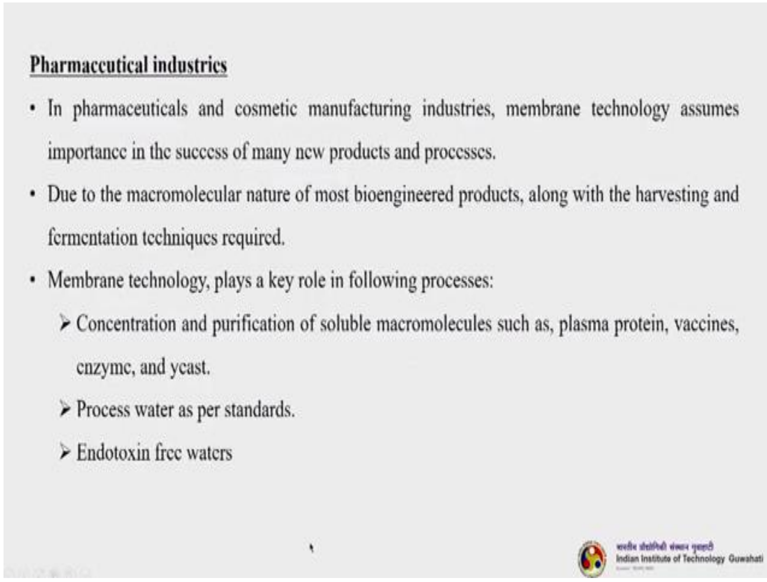

So then next is the pharmaceutical industry. In pharmaceutical or many times it is called as bio pharmaceutical industries membrane has a lot many applications, so due to the macro molecular nature of most bio-engineer products along with the harvesting and fermentation technologies some membrane like ultra filtration and micro filtration plays a vital role in doing the separation so membrane technology plays a key role in following applications.

So concentration and purification of soluble macromolecules such as plasma protein, vaccines enzyme, yeast and even the antibodies process water as per standards because ultra pure water is required for biotechnological applications and in pharmaceutical industries and endotoxin free waters.

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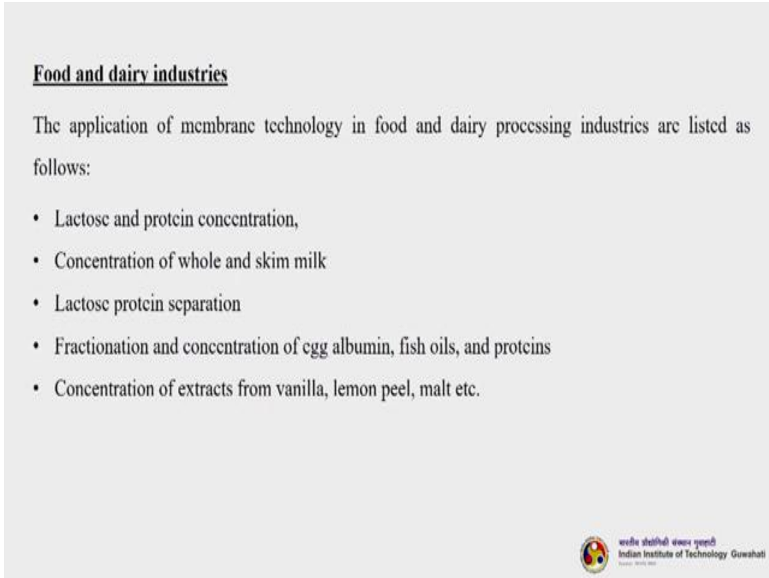

In food and dairy industries the lactose and protein concentration we use usually either microfiltration and ultrafiltration membranes, the concentration of whole and skim milk we use micro filtration membranes, lactose protein separation, ultra filtration magma computation both can be used so fractionation and concentration of egg albumin, fish oils proteins.

Concentrations extracts from vanilla lemon peel malt etc, can be achieved by that either by using ultra filtration or even pervaporation membranes.

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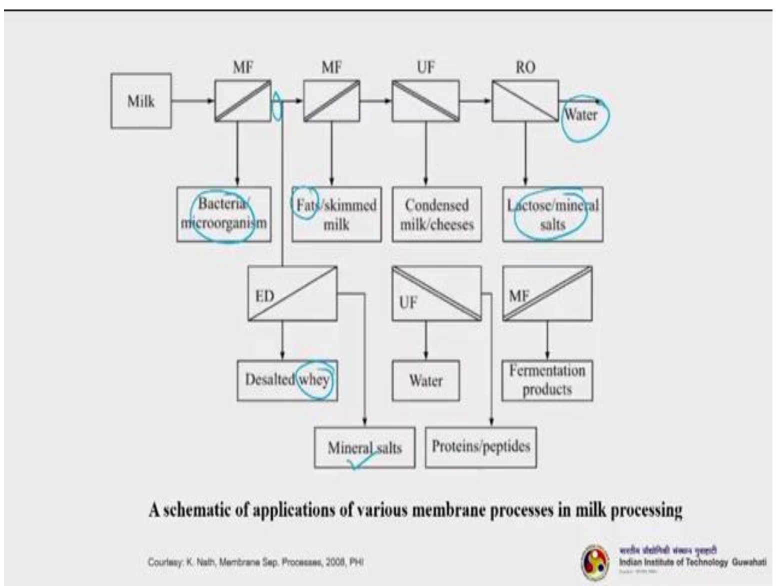

So let us see this is one classical example of a schematic applications of various membrane processes in milk production or milk processing industries, dairy industry basically you can see the milk first goes to the micro filtration unit here, where it removes the bacteria and microorganisms then it goes to another micro filtration units where the fats will be removed so we will get basically skimmed milk.

Then again it process through a ultra filtration unit where we will get condensed milk or cheese and then it passes through a reverse osmosis membrane where we get water here, and lactose general salts here, so the stream from here it can go to a electro dialysis unit where the product is diesel the salted ware and we get mineral acids here similarly we can use ultra filtration and micro filtration to separate proteins peptides.

And as well as other fermentation products so this this schematic representation makes us understand that how different membrane processes such as ultra filtration micro filtration RO and ED plays important and vital role in milk processing or dairy industries

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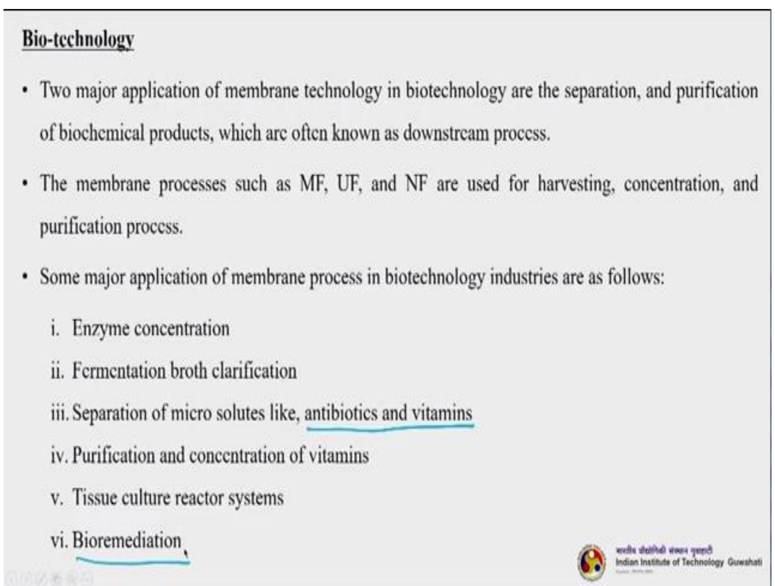

So the next application is biotechnology industries, so two major applications of membrane technology in biotechnology are the separation and purification of biochemical products which are upon known as the downstream processing. So in most of these industries the downstream processing part which means the purification or removal of the product from the fermentation broth or the solvent in which they are present is called downstream processing.

And that cost is almost 40-50 percent of the entire cost of the product some membrane processes such as microfiltration ultrafiltration nanofiltration are used for harvesting concentration and purification processes some major applications are enzyme concentration, fermentation, broth clarification, separation of micro solutes like antibiotics and vitamins purification of container purification.

And concentration of vitamins tissue culture reactor system and bio remediation so bio remediation is again a waste water treatment process in which we remove or remediate various organic compounds present organic and toxic compounds present using various microorganisms. So the next slide it tells us about the application of membrane technology in bio processing industries.

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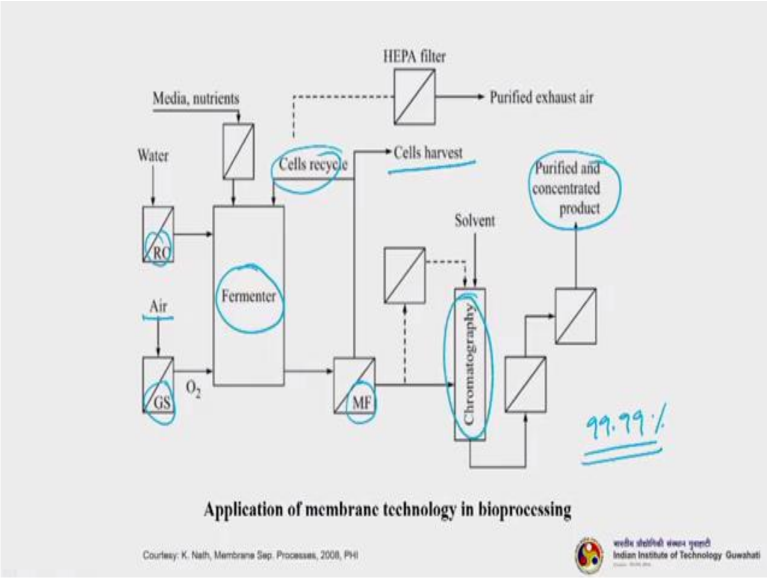

You can see that this is a fermenter which is doing the fermentation okay to which we will use actually media and nutrients and we need water for that, and you can see there is aero process here so what does that type water which is coming from the tab is being feed to the RO system and it will give us a pure water which is being fed to the fermenter and then air is a oxygen is required for the fermentation the micro organisms.

So oxygen is being purified using a gas separation membrane from the ambient air. So now once the fermentation is happening so we need to remove some of the cells so this cells can be either dead cells or the mature cells so we remove the cells using micro filtration some of the cells can be recycled back okay to the fermenter to maintain a proper biomass and some of the cells will go to the harvesting for the product.

Then from here we can place another membrane separation unit okay and it will be paired to the chromatography system where we can get the purified and concentration product please understand that chromatography is one of the most important and the most important and the only important process which will give us more than 99.99% pure product this is the only process which will give us such a purity.

No other process even if it is membrane also will not give us so much up from pure product so the finishing stage is more in most of the biotechnology by pharmaceutical industries is always the chromatographic separation. So we understand that how various membrane processes whether it is gas separation, whether it is reverse osmosis, whether it is micro filtration is being utilized in a bio processing industries.

To purify products as well as remove some contaminants from the product stem so with this we come to the end of this particular lecture today so students these are some of the.

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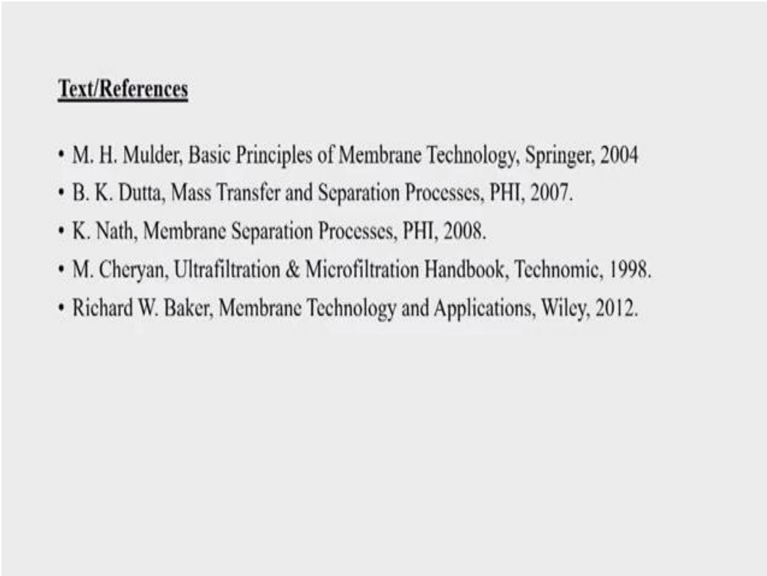

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Textbooks and references book from which I have taken the materials. Mulder that is the most important book which I am referring basic principles of membrane technology, B K Dutta, mass transfer and separation processes, professor koshik Nath's book on membrane separation processes this is by prentice hall India then Cheryan's books on ultra filtration and micro filtration handbook.

And Richard Becker's book on membrane technology in applications so you can refer these books for more detailed understanding of the processes so thank you very much and in the next class we will cover this following syllabus.

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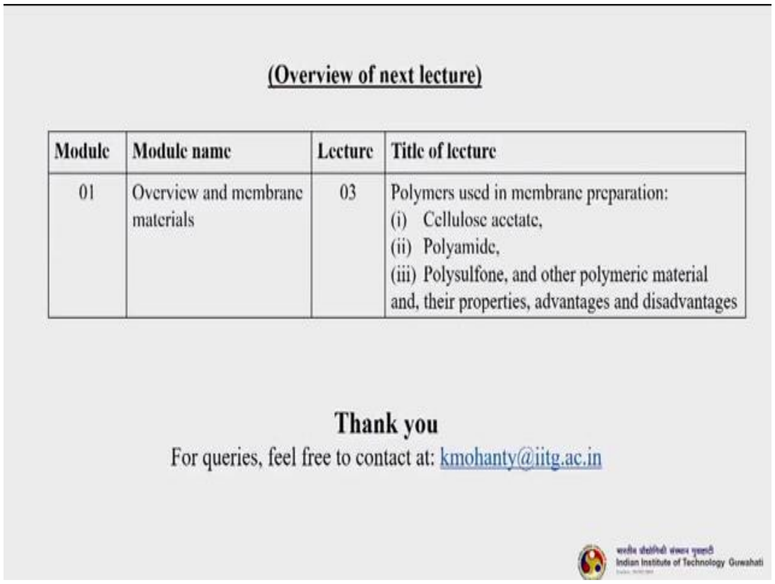

(Overview of next lecture)

Module	Module name	Lecture	Title of lecture
01	Overview and membrane materials	03	Polymers used in membrane preparation: (i) Cellulose acetate, (ii) Polyamide, (iii) Polysulfone, and other polymeric material and, their properties, advantages and disadvantages

Thank you

For queries, feel free to contact at: kmohanty@iitg.ac.in

So we will try to understand that three or four different types of materials which will be utilized to prepare membranes. So we will be discussing membrane materials in the next one or two classes so we will discuss about cellulose acetate, polyamide, polysulfone, polyethersulfone all these membrane materials their properties and their advantages and disadvantages. So thank you very much you can write to me at kmohanty@itg.ac.in if you have any query and I will definitely try to replay you within a stipulated time, thank you very much.