Chemical Process Intensification
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Lecture 11.1
Introduction to Membrane and its Principles

Welcome to massive open online course on Chemical Process Intensification. So we start here the topics on process Intensification by Membrane as a module 11. Now under this module we will discuss something about the Membrane and its Principles.

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We know that there are several aspects of process intensification in chemical engineering discipline in that case member is one of the important process intensification where the chemical process can be carried out by enhancing its, mass transfer as well as, some other characteristic of the processes.

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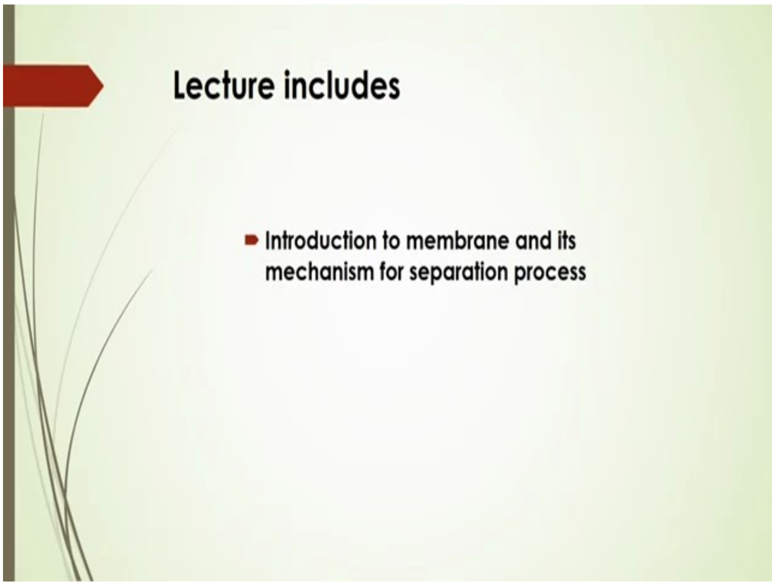

And because of which actually this is one of the most important part of chemical engineering, process intensification, so in this lecture we will try to introduce something about that membrane and how it works and it is mechanism for the separation process.

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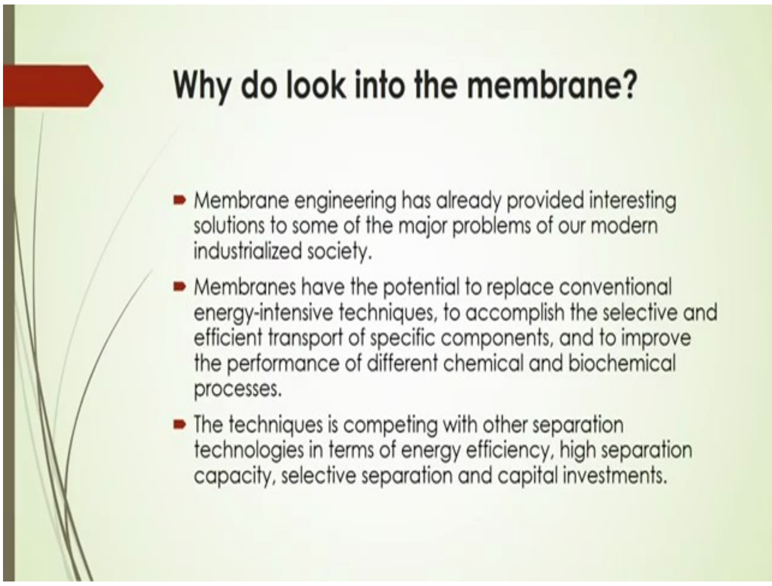

Now first of all of course it will come to your pitcher that why we should need this membrane because there are lot of other, process principles or process technologies are there to, that utilize different separation processes, so in that case why membrane will be important in that aspect for separation process in chemical engineering aspects.

So in that case that there are several solutions that has come by this membrane process in our modern industrialized society. In that case it has some potential to replace conventional energy intensive techniques to accomplish the selective and efficient transport of specific components and to improve the performance of different chemical and biochemical processes.

And these techniques of membrane separation it is actually competing with the other separation techniques in terms of energy efficiency and high separation capacities, selective separation and capital investment. So because of these advantages of this energy intensive process energy intensive separation by this membrane process, so it is gaining day by day interest for the community of industry as well as academic section for intensify further that chemical process by membrane process because it has that several aspects of potential to give that better efficiency of the process with less energy consumption.

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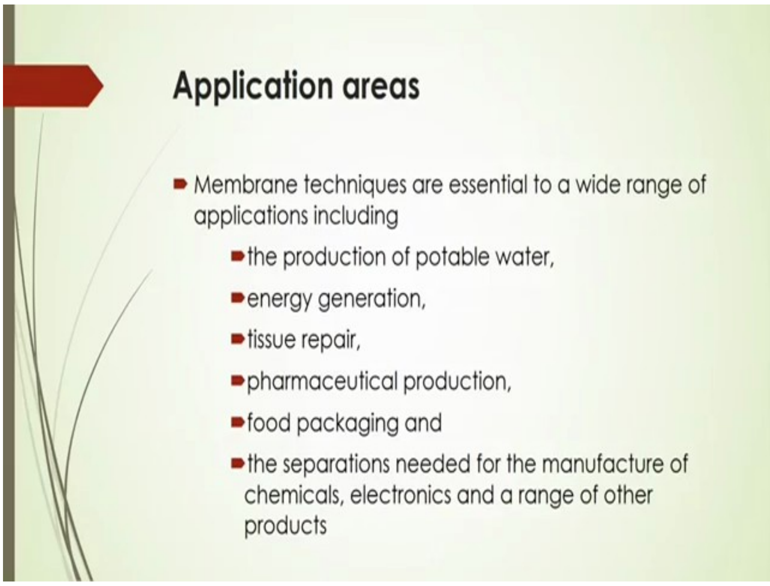

And of course there are several areas of applications for this membrane processes like that it can be used for the production of potable water, it can be used for energy generation, it can be used for tissue repairing, it can be used for pharmaceutical production even food packaging this type of process, membrane process are also being used and the separations that are needed for the manufacturer of chemicals even electronics and a range of other products this membrane is more important.

Mainly for the separation process is very important and it is used widely in industry though up to a certain scale it is applicable but presently there are several researches going on the membrane how to actually procured that membrane, we synthesize the membrane to get the better efficiency even for specific separation processes are different types of membranes how it can be actually case to case to be used for to better process performance by this memory.

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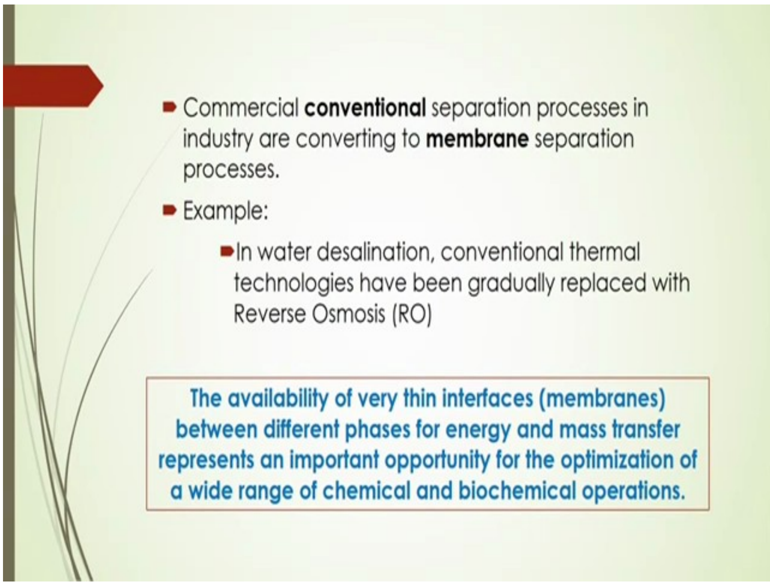

And you will see that, commercial conventional separation processes in industry generally converting to membrane separation processes because of course it has several advantages that we have discussed that it is energy-efficient process and also it may give that sometimes around 100 percent efficiency for the separation process. We will see that as an example we can say that in water desalination.

Desalination process there conventional technologies are actually being used and it is being actually gradually replaced with reverse osmosis process which is also one of the important part of this membrane separation and in this case the availability of very thin interfaces that is even by membranes between two phases for energy and mass transfer that will represent an important opportunity for the that optimization of a wide range of chemical and biochemical processes. So that is why the commercial conventional separation processes in industry are converting to the membrane separation processes.

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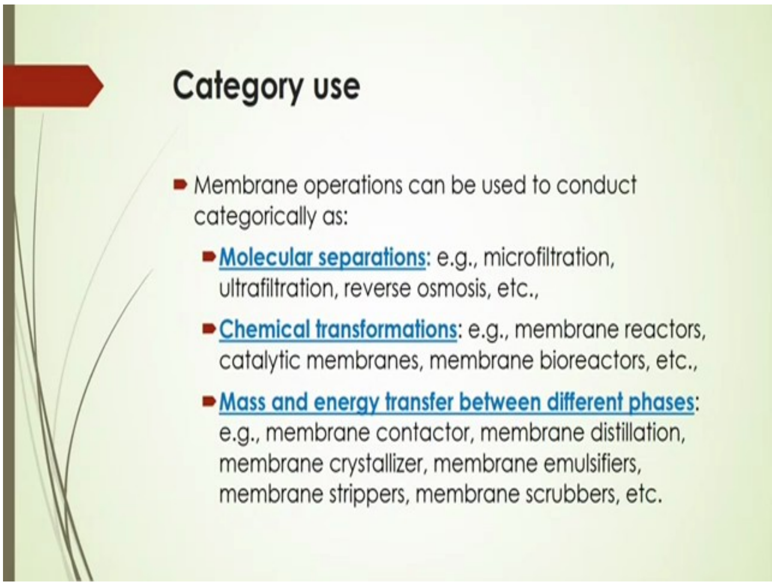

And what are the different that uses categorically by having that process intensification by this membrane. So in that case this Membrane operations can be used to conduct the operations or chemical processes categorically as like for the molecular separations even in the case of chemical transformation in the case of mass and energy transfer between different phases.

In the case of molecular separations like microfiltration even ultrafiltration, reverse osmosis etc. are the part of this molecular separation process. Even chemical transformations where membrane reactors, catalytic membranes even membrane bioreactors are actually coming as a process intensified unit for the transformation of the chemicals.

And also for the mass and energy transfer between a different pages like membrane contactor, membrane distillation, hybrid system of membrane and also that catalytic reactions, so it is called membrane reactors, membrane crystallizers, membrane sometimes that to produce that emulsification of this gas liquid or liquid-liquid system, so it would be or it is being used as membrane emulsifiers, membrane strippers also sometimes to absorb some, gaseous particles or liquid molecules into the solid particles, the membrane sometimes is giving that intensified way of efficiency of that process.

And also membrane covers just separating of the gaseous molecules by the membrane. So these are the actually main three category of this application of the membrane for different chemical processes. So in that case you have to just categorically select the membranes where you can apply for particular case to case application of chemical processes.

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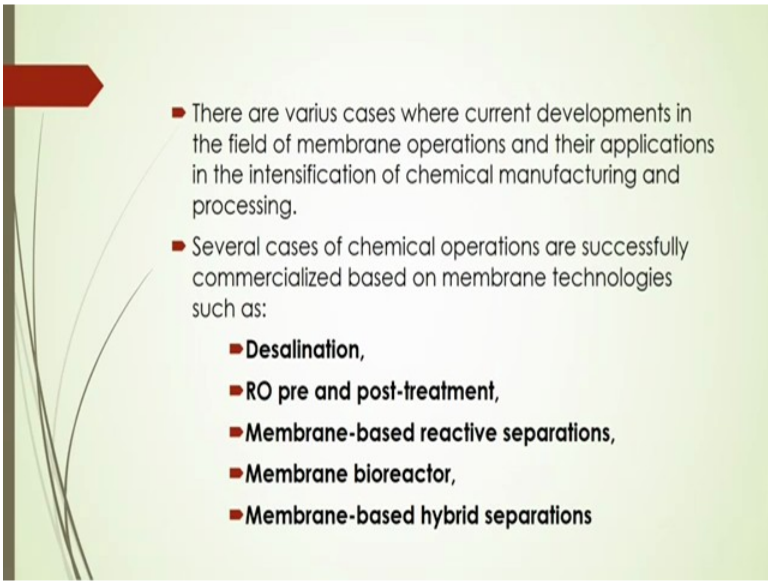

There are various cases where current developments in the field of membrane operations and their applications in the intensification of chemical manufacturing and processing also there and also you will see that several cases of chemical operations are successfully commercialized based on the membrane technologies such as desalination, reverse osmosis pre or post-treatment even membrane based reactive separations, membrane bioreactor, membrane-based hybrid separation.

We have actually discussed lot of things about that process intensification by the hybrid processes like membrane distribution, membrane reactive distribution that we have discussed in our earlier modules also there. So in this case we can say that this and commercial sector this membrane can be used for this desalination process even for pre-and post-treatment of reverse osmosis even membrane based reactive separation membrane bioreactor which has been used for separating that that different porting particles even other things.

And membrane-based hybrid separations are also, there are different types of hybridization like membrane crystallization, membrane reaction, membrane emulsification application, membrane stripping, membrane scrapping this type of hybrid separation process would be based on this membrane.

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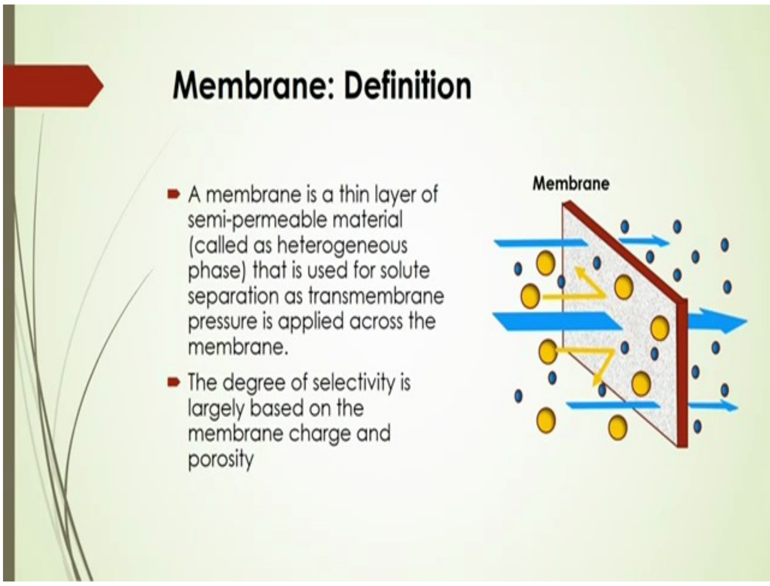

Now question is that, what is that membrane? How you will define that membrane? Basically the membrane is a thin layer of semi permeable material which is called heterogeneous phase and that is used for solute separation as trans-membrane pressure is applied across the membrane. So it is actually a thin layer as shown in the slide in the figure that this is one thin layer of semi permeable material through which that molecules will be transferring from one phase to another phase or one mixture to the other mixture.

As by different mechanism maybe pressure gradient maybe concentration gradient maybe that other driving forces will be applied, so that through that semi permeable material the molecules will be transferring and also it is based on characteristics of the membrane and the degree of selectivity is largely based on the membrane charge and also porosity. So there is one important factor that membrane is nothing but the porous material through which that molecules will be transferred based on their size.

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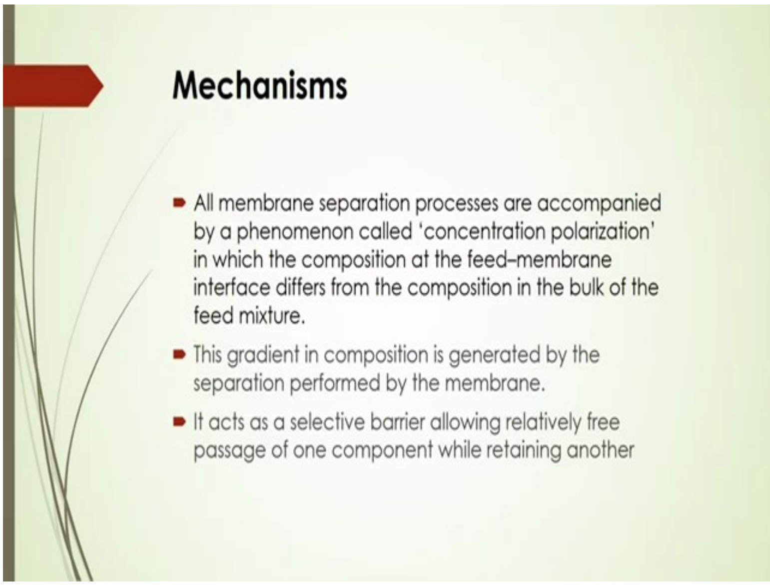

So what is the mechanism for that? So all the membrane separation processes are accompanied by phenomenon that is called concentration, polarization in which the composition at the feed membrane interface that will differ from the composition in the bulk of the feed mixture and the gradient that is in the composition is generated by the separation that is performed by the membrane.

And you will see that it acts as a selective barrier that will allow the relatively free passage of 1 component while another will be retain there in the solution. So we can say that there will be a certain gradient of composition based on which that components will be transferring from one place to another through the membrane. And mainly this gradient as concentration gradient but of course there will be some pressure of course will be difference between these two parts of the membranes that we will show discussed already.

We know that there will be some pressure here, so because of that pressure gradient there will be transfer and in the liquid only without membrane you will see that there will be concentration gradient based on which there will be a transfer of molecules from one location to the another location based on that concentration difference. Even also here if there is a semi permeable membrane will be placed in the solution you will see because of that concentration gradient you will see through the pores of the membranes that very small molecules that is smaller than the pores of the membrane that will be passed through the membrane.

So that will be a separation whereas the molecules whose size will be larger than the pores of the memory that would be retained in the feed side and so this is your feed side at this another is called that permeate side. So feed side it is called that we tainted side and another is called permeate side.

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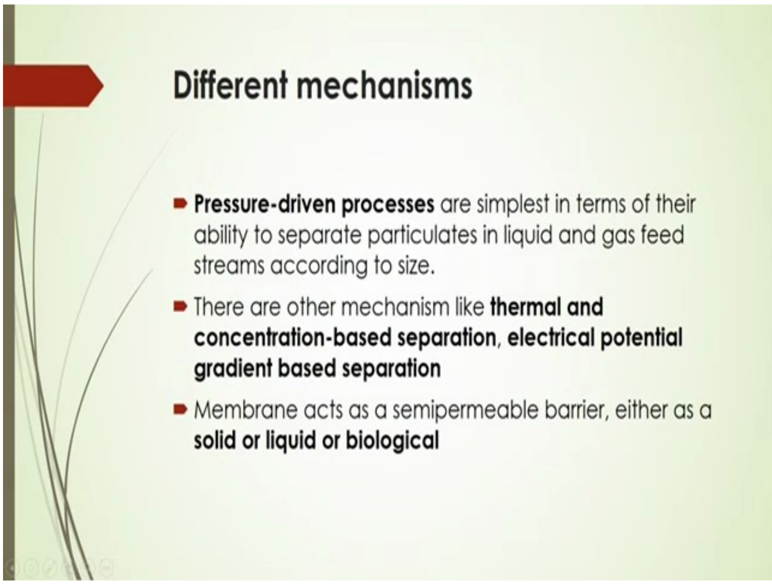

So in this way we can say that not only this concentration or gradient there will be other mechanism of having this transfer of molecules from feed to the permeate side of this membrane. So pressure driven process are the simplest in that case which in terms of their ability to separate particulates in the liquid and gas feed stream is according to size.

There are other mechanisms like thermal and concentration-based operations and also electrical potential gradient based separation also will be there. In that case you will say there will be some temperature gradient and also some electrical potential gradients will be there based which that separation will be there through this membrane. And also membrane acts as a semipermeable barrier either as a solid, liquid or biological.

There are three types of membrane you will see, maybe solid membrane, maybe liquid membrane and also other biological membranes, so 3 types of membranes will be there. We will successfully discuss that different types of membrane.

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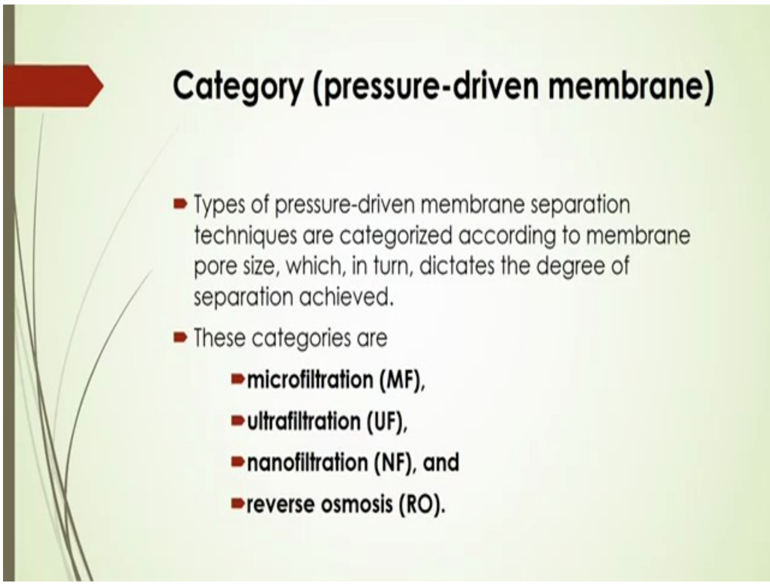

Now if we consider that the pressure driven membrane that is where that membrane separation techniques are categorized according to membrane pore size. In that case you will see it will dictates the degree of separation based on the size of the pore of this membrane. So in that case those membranes based on their pore size it will be classified as microfiltration, ultra filtration, nano filtration and also reverse osmosis.

So microfiltration will be there micron sized particles will be there. Ultra filtration even smaller, nano filtration even smaller particles will be separated. Even reverse osmosis also there will be based on the pressure gradients separation will be there.

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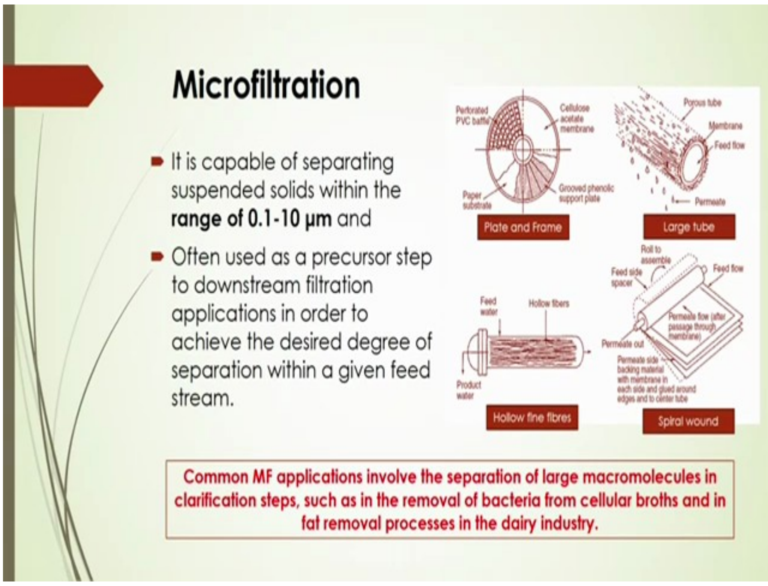

Now if we consider that microfiltration, it is actually capable of separating suspended solids within the range of 0.1 to 10 micro-meter and also it will often use to precursors step to downstream filtration application in that case you can achieve the desired degree of separation within a given feed stream by this type of microfiltration process. And here in this slide there are several type of microfiltration-based membrane are produce like plate and frame type membrane, large tube membrane and hollow fine fiber spaced membrane or spiral wound membrane are there. So common microfiltration based membranes are applied which is involved in the separation of large macromolecules in clarification steps such as in the removal of bacteria from cellular broths and also in you can say that fat removal processes in the dairy industry.

And also you can say that there are other applications are there based on plate and frame system, large tube system, hollow fibre system, spiral wound system, microfiltration to separate this type of particles within the range of 0.1 to 10 micro-meters.

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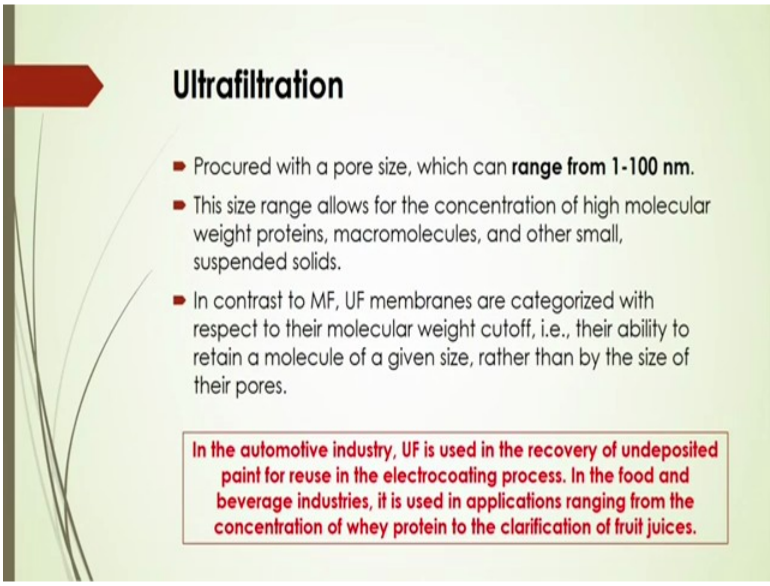

And we procured with a pore size which can range from 1 to 100 nanometer that is called Ultra filtration and this size range allows for the concentration of high molecular weight proteins, even macromolecules and other small suspended solids. So this type of ultrafiltration are being used for this type of separation processes and in contrast to microfiltration this ultrafiltration membranes are actually categorized with respect to their molecular weight cut-off.

In that case their ability to retain a molecule of a given size rather than by the size of their pores. So you have to remember that in the automotive industry ultrafine membrane is generally used in the recovery of undeposited paint for reuse in the electro-coating process and also you can say that in the food and beverage industries it is used in applications like ranging from the concentration of whey protein to the clarification of fruit juices.

So this type of applications are being actually carried out based on this ultrafiltration where you have to separate the molecules within a range of 1 to 100 nanometer.

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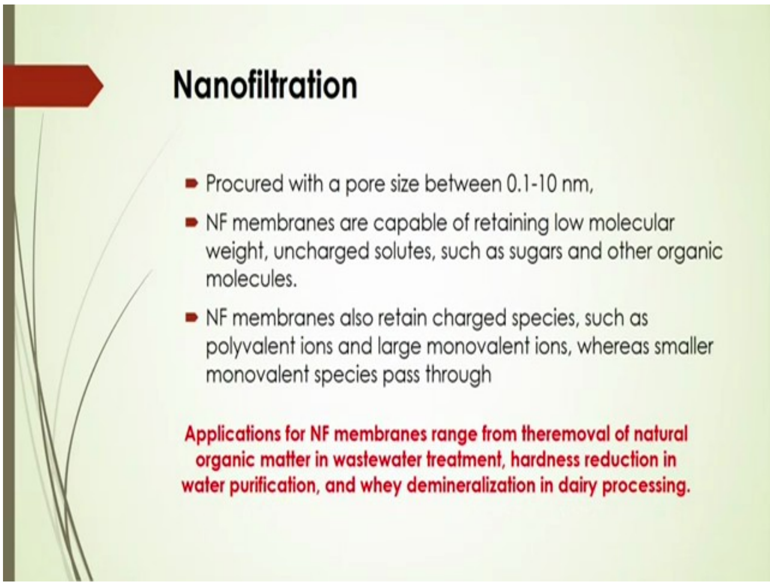

And also we will see another type it is called Nanofiltration. It is a more reduced pore size of the membrane and in that case it is procured with a pore size between 0.1 to 10 nanometers and this type of membranes are capable of retaining very low molecular weight compound and it is also used for retaining uncharged solutes like sugars and other organic molecules.

And also you will see that this Nanofiltration membranes also retain some chargeable spaces like polyvalent ions and also large monovalent ions. Whereas you can say that smaller monovalent spaces also are there to be passed through that membrane. So that is why it is being applied in the ranges of application form you can say that removal of natural organic matter in wastewater treatment, hardness reduction in water purification and also whey demineralization in dairy processes.

So these are the applications where you can use this Nanofiltration based on the size of the molecules as well as you can say that charged and uncharged solutes within a size range of 0.1 to 10 nanometer.

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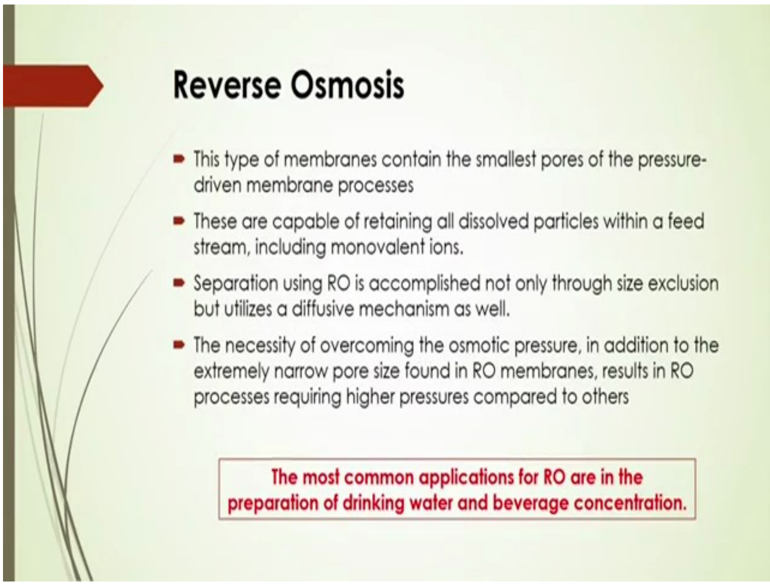

And another important aspects of that membrane separation it is called reverse osmosis. In this case you will see that this type of membrane contain the smallest pores of the pressure driven member processes and in this case you will see the separations will be based on that reverse osmosis which is accomplished not only through the size exclusion but utilizes a diffusive mechanism there.

And in that case these are capable of retaining all dissolved particles within a feed stream may be including monovalent ions and in this case you have to remember that it is required to work on the osmotic pressure in addition to the extremely narrow pore size that is found in reverse osmosis membranes and it may result in reverse osmosis processes which will require higher pressure compared to the others membranes.

And most common applications for this reverse osmosis are in the preparation of drinking water and beverage concentration. So this you have to remember.

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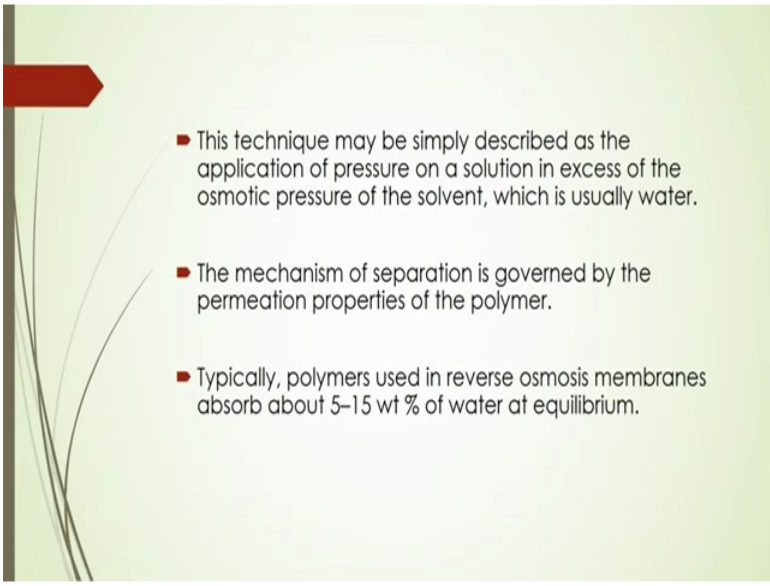

And this technique may be simply described as the application of pressure on a solution in excess of osmotic pressure of the solvent which is usually water and this mechanism of separation by reverse osmosis membrane is governed by the permeation properties of the Polymer and different types of polymers actually are being used for procuring this type of reverse osmosis membranes.

And in that case typically you can say that Polymers that is used in reverse osmosis membranes that will absorb about 5 to 15 weight percent of water at equilibrium.

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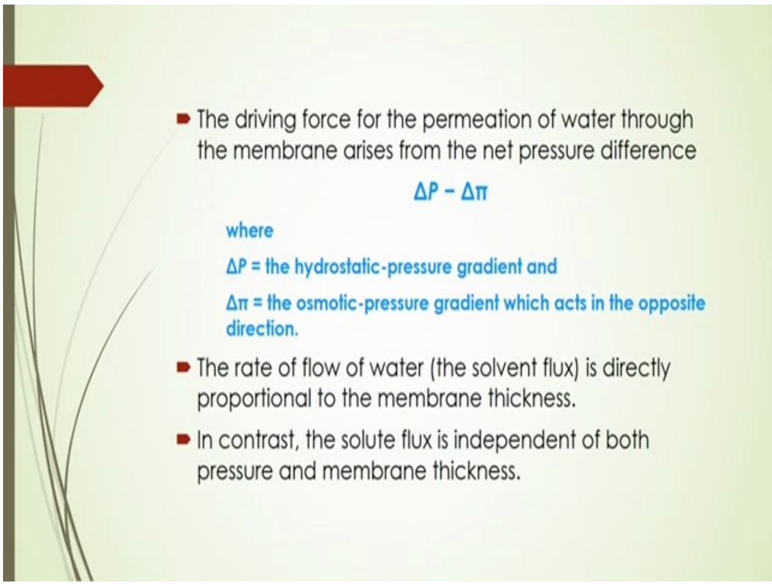

And in that case the driving force for the permeation of water through the membrane that is arises from the net pressure difference like here the difference will be ΔP minus $\Delta\pi$ were ΔP is the hydrostatic pressure gradient and $\Delta\pi$ it is called osmotic pressure gradient which acts in the opposite direction. And in this case the rate of flow is very important where the solvent flux, you can say that this rate of flow of water is directly proportional to the membrane thickness.

And in contrast for the solute flux is independent of both pressure and the member thickness. So you have to remember that the flow rate of course how it can be designed or how it can be actually chosen for operation that based on this your membrane thickness and also you cannot assess it based on the solute flux because the solute flux is independent of both pressure and membrane thickness.

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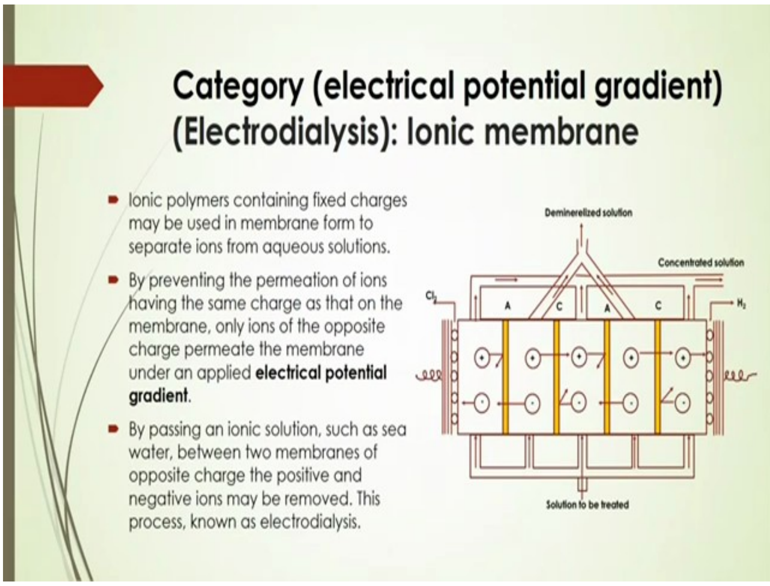

And another category other than this pressure it is called electrical potential gradient-based membrane. It is sometimes called ionic membrane. This ionic polymeric membranes are containing fixed charges be used in membrane formed to separate ions from aqueous solution and in that case you can say that by preventing the permeation of ions having the same charges is that on the membrane. Only you can say that ions of the opposite charge permeate the membrane under an applied of electrical potential here.

So you can say some membranes where this electrodes and based on this electrical potential gradient this charge will be moving through that membrane. So by passing an ionic solution such as seawater between 2 membranes of opposite charges, the positive and the negative ions may be removed and this process is known as Electrodialysis. So Electrodialysis is basically a membrane process where the driving force is nothing but that electrical potential gradient where it is sometimes called as ionic membrane.

Because these ionic polymers that containing fixed charges which is used in membrane formation to separate ions from aqueous solution.

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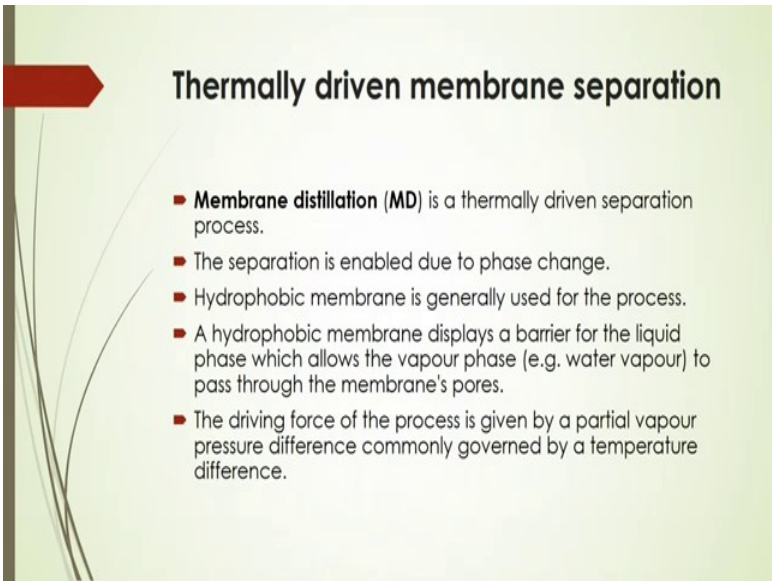

Another driving force based membrane it is called thermally driven membrane separation. And in that case membrane distillation is one of the important membrane processes where it is actually operated based on the thermally driven separation process. And the separation is enabled due to the phase change. In that case we will see that hydrophobic membrane is generally used for the process.

And also you can say that the driving force of the process is driven by the partial vapor pressure difference which is governed by a temperature difference. And in this case you have to use the hydrophobic membrane in nature which displays a barrier for the liquid phase and also it allows the vapor phase for example like water vapor to pass through the membrane pores.

So this is important aspects of membrane separation where pressure difference commonly governed by a temperature difference.

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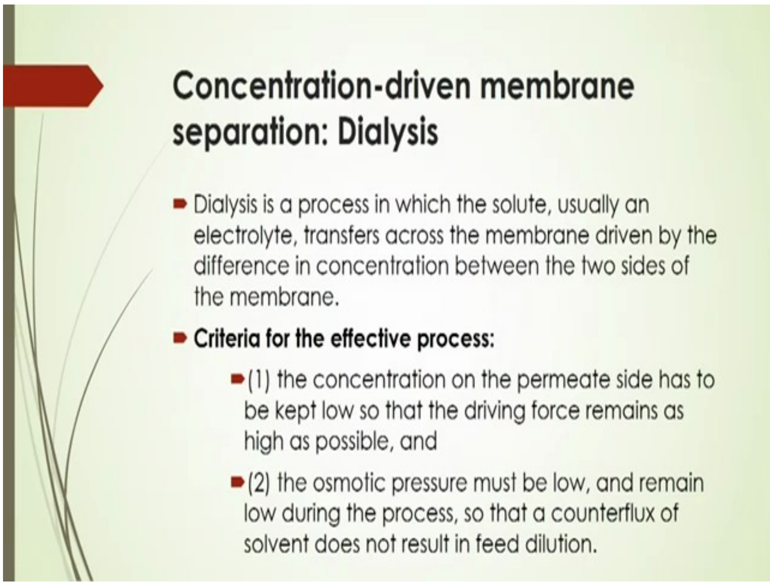

And another very important and mostly used membrane separation is called concentration driven membrane separation which is called Dialysis and Dialysis is a process in which that solute usually an electrolyte transfers across the membrane that is given by difference in concentration between the two sides of the membrane. And in this case what should be the criteria for the effective process.

At the concentration on the permeate side has to be kept low, so that the driving force remains as high as possible, so that the transfer of the molecules through the membrane will easily happen. And osmotic pressure must be low and also remain low during the process, so that a counterflux of the solvent does not result in feed dilutions. So that is to be remembered.

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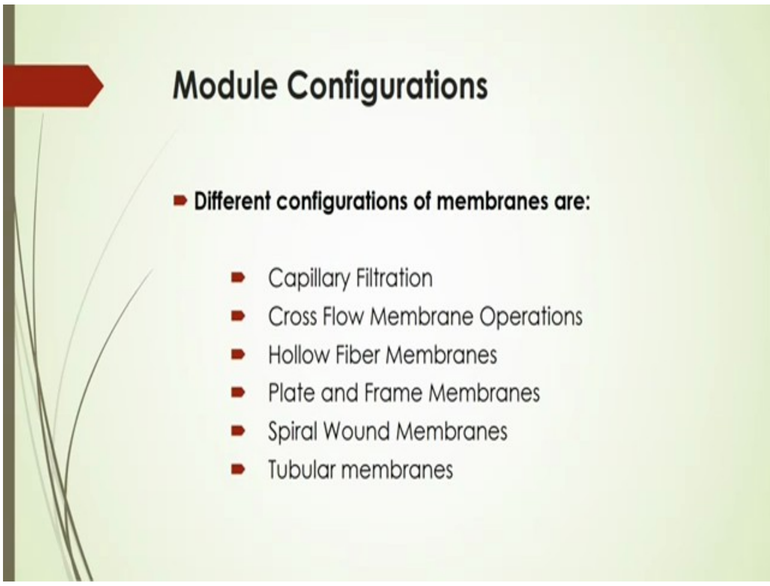

And of course different types of membranes will be applied for specific applications and of course based on the pore size ultrafiltration, Nano filtration, even microfiltration whatever it is and of course this type of membranes that is being procured based on that what the mechanism of that separation whether it is the pressured driven whether it is thermally driven or electrically driven or not that things.

But out of that also there are several configurations of the membrane which are being used for process intensification like Capillary Filtration system. Cross Flow membrane operations, Hollow Fiber membranes, Plate and Frame membranes, Spiral Wound membranes and even Tubular membranes these are the different configurations of the membranes which are being used for the specific applications for its process intensification of separation.

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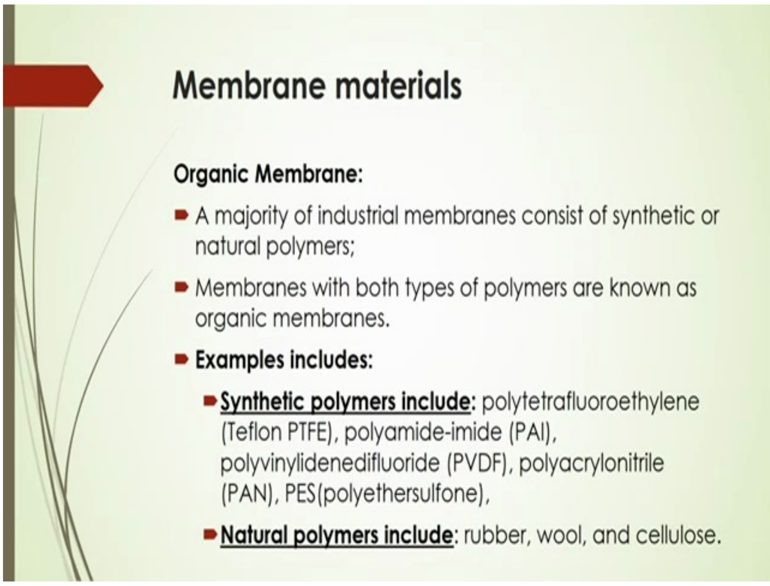

And in that case you have to consider that material types whenever you are going to procure different configured membranes. So generally different types of organic chemical based membrane is procured even you can say metallic membranes are being procured.

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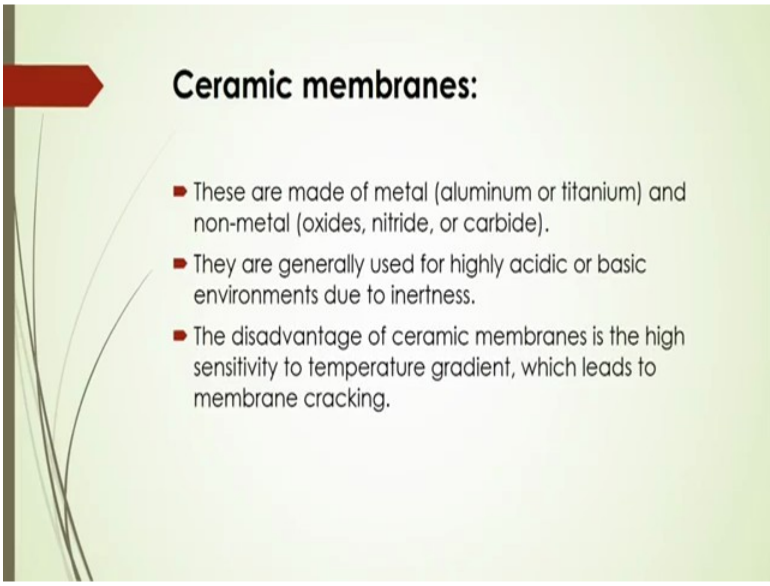

Ceramic membranes are being procured.

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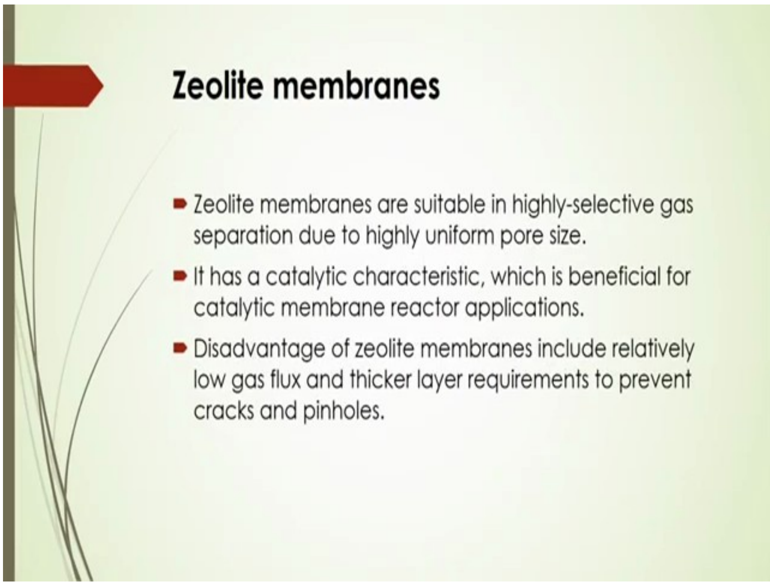

Even different types of metals like Zeolite membranes are there.

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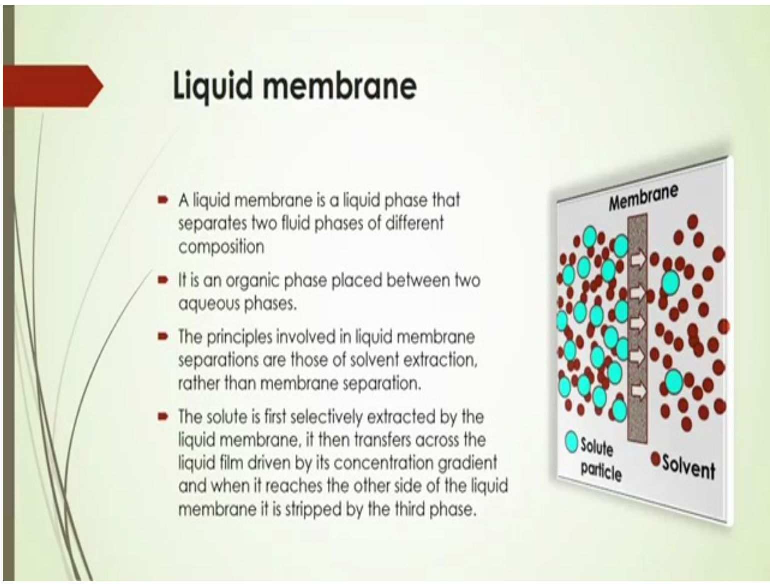

Liquid membranes are there. Different types of membranes are there based on that procuring materials.

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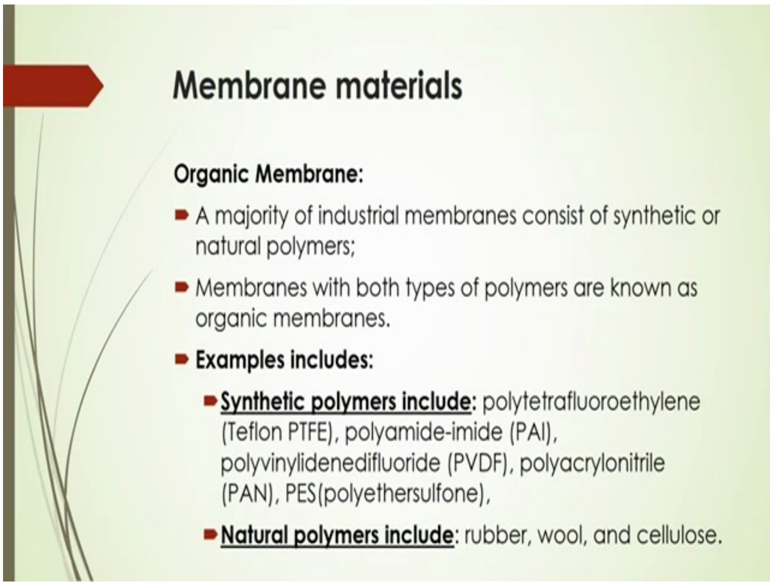

So as per that organic membrane, a majority of industrial membranes that consist of synthetic or natural polymers there. And in that case membranes with both types of polymers are known as organic membranes whether it is synthetic or natural polymers for example like synthetic polymers that will include that Polytetrafluoroethylene that is Teflon PTFE type material which is being used for membrane procurement. Polyamide membrane also it is called PAI membrane.

Polyvinyl the Nitrovinyl that is PVDF membrane even Polyyacrylonitrile membrane it is called PAN membrane and also PES membrane is also there, it is called Polyethersulfone membrane are there so the membranes actually these names are there based on chemical synthesis procured membrane and natural polymers also there to procure that membrane like rubber, wool and cellulose, this type of membranes are also there.

So based on their material how it is being procured and how it can be categorized.

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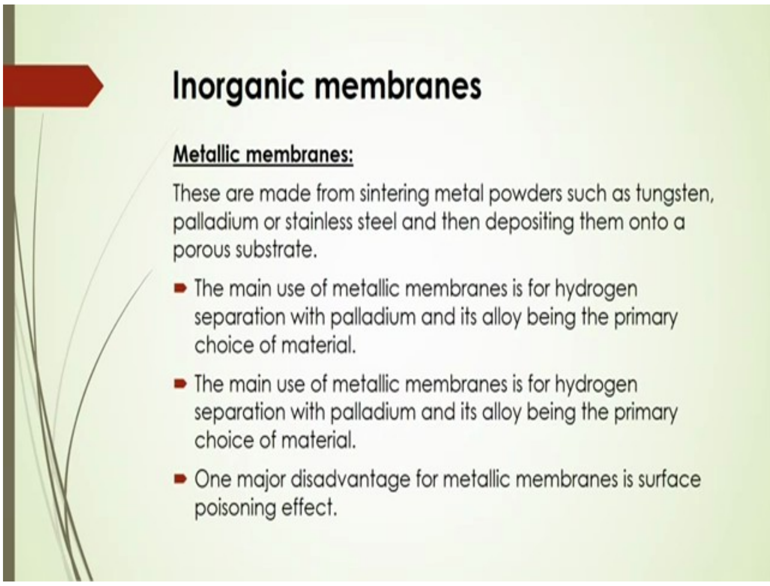

And in organic membranes like metallic membranes, in this case this type of membranes are being made from sintering metals such as tungsten, Palladium or stainless steel and then depositing them into a porous substrate and the main use of metallic membranes is for hydrogen separation with palladium and its alloy which is being the primary choice of material there.

And also the main use of this metallic membrane is for surface poisoning effect there which is not actually suitable for using of this type of metallic membranes. This is one disadvantage for that metallic membranes which are procured based on that tungsten, Palladium or stainless steel.

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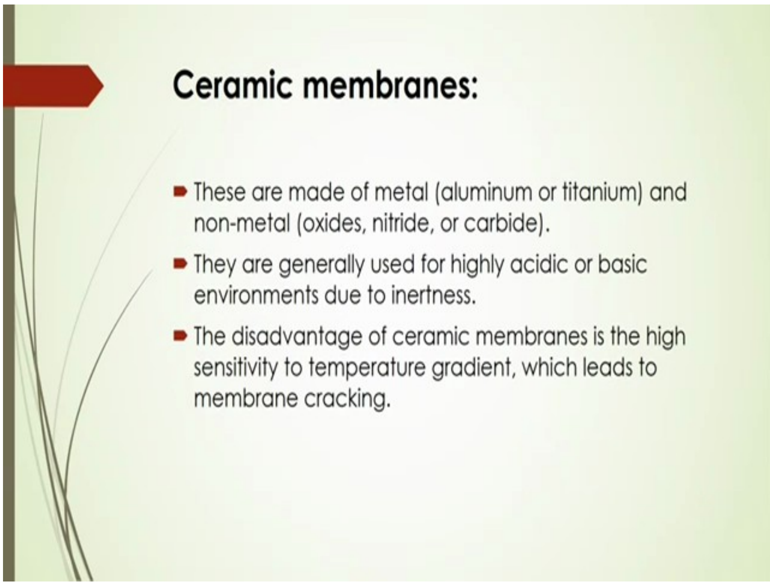

And also we can have other type of materials like ceramic type of membranes and these are made of metals like aluminum or titanium and also non-metal oxides like oxide, nitride and Carbide, this type of nonmetals are being used along with aluminum and titanium. So this is called that ceramic membranes they are generally used for highly acidic or basic environments due to inertness.

And the disadvantage of the ceramic membrane is the high sensitivity to temperature gradient which leads to membrane cracking. So this is the disadvantage where you cannot operate this membrane at high-temperature.

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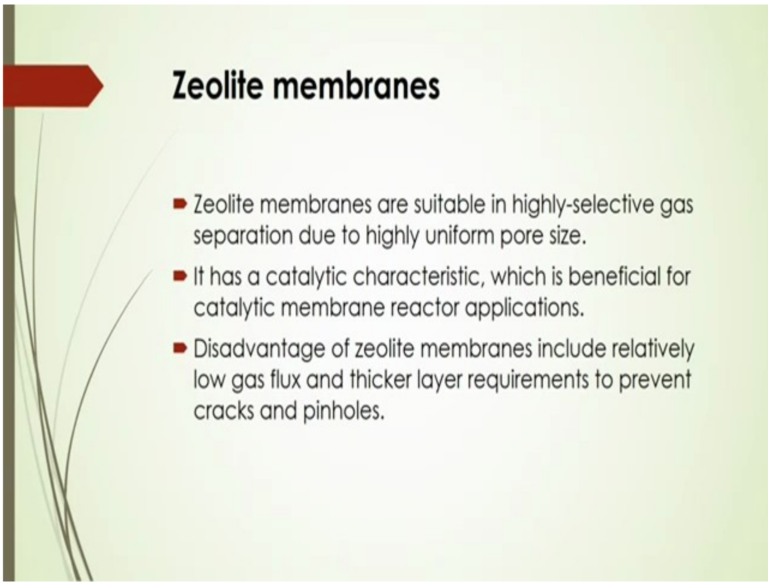

Another one important membrane it is called Zeolite membrane this type of membranes are generally used for highly selective gas separation due to highly uniform pore size and it has a catalytic characteristic which is beneficial for catalytic membrane reactor applications but there is a disadvantage like it includes relatively low gas flux and thicker layer requirements to prevent cracks and you can say that it is called Pinholes.

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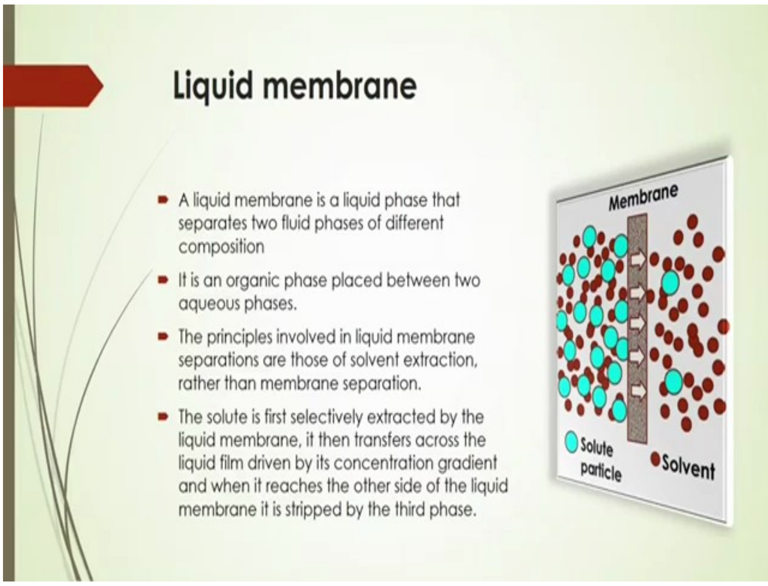

Other category out of that metal or chemical, ceramic or organic, chemicals or metal-based membrane, nowadays for specific application of solvent extraction or you can say that separation of the organic molecules in a solution without using that solid material the membranes are being procured which is called that liquid membrane. In this case a liquid phase that separates 2 liquid phases of different compositions.

So one liquid phase will be acting as a membrane there. It is an organic phase that is placed between 2 aqueous phases and the principals involved in the liquid membrane separation are those of solvent extraction rather than membrane separation and in this case the solute is passed selectively extracted by liquid membrane and then it is being transferred across the liquid film that is driven by its concentration gradient and also when it reaches the other side of the liquid membrane it is shaped by the third phase there.

So basically the solute first actually extracted by that liquid membrane and then it transfers across the liquid film driven by its concentration gradient. After that there will be a third phase which is being used for suppression of those transferred materials to the liquid membrane and that is generally being stripped by that third phase.

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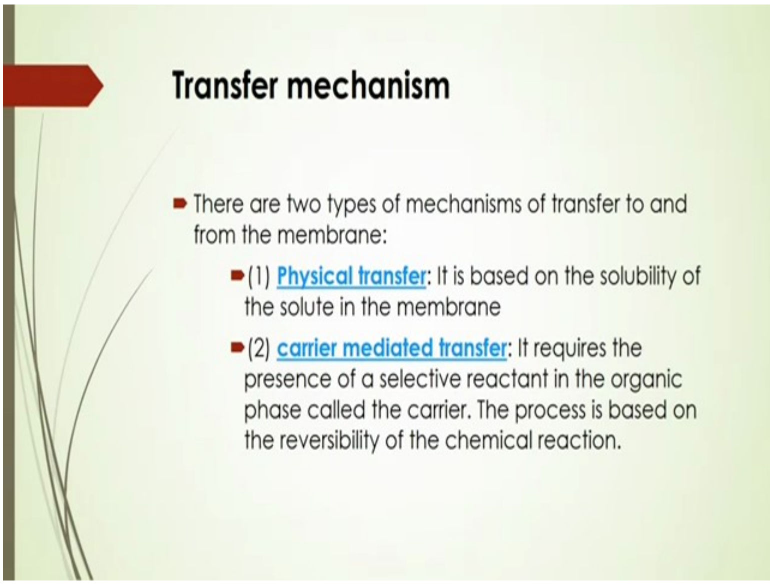

And there are two mechanisms of transferring of that molecules after that liquid membrane, generally physical transfer another is Carrier mediated transfer. In case of Physical transfer you will see the solubility of the solute in the membrane is the main important driving force and also Carrier mediated transfer in that case it will require the presence of a selective reactant and the organic phase that is called carrier and in that case it is based on the reversibility of the chemical reaction.

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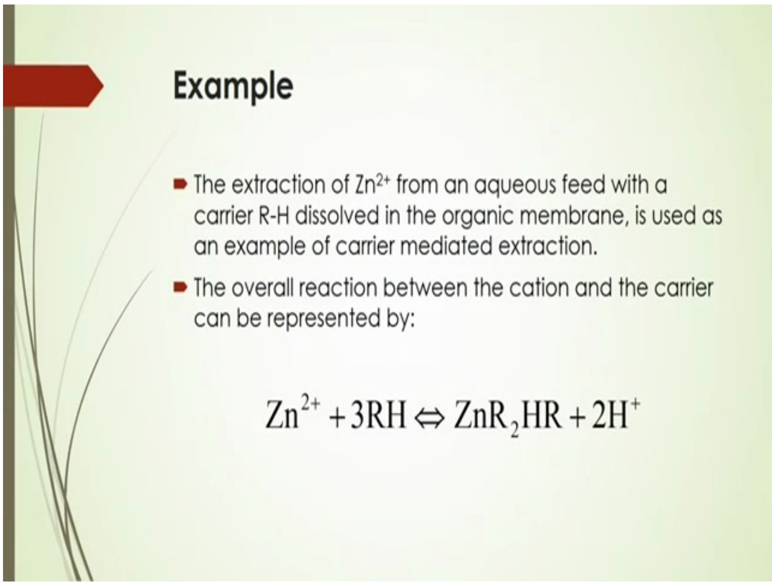

Example like that extraction of zinc ion from an aqueous feed with a carrier RH dissolved in the organic membrane which is used as an example of Carrier mediated extraction and the overall reaction between the cation and the carrier that can be represented by this equation that is given in the slide.

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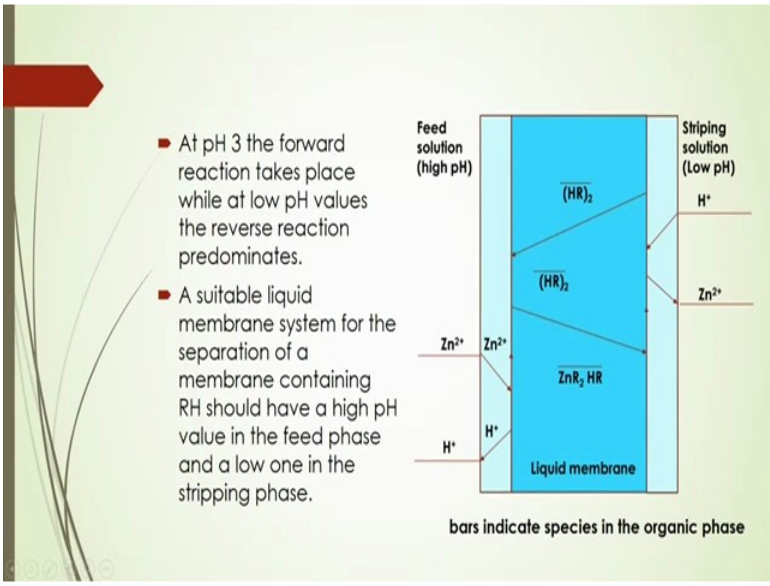

And in that case that at pH 3 the forward reaction that takes place while at low pH values the reverse reaction predominates as per shown in the figure in the slides and in that case a suitable liquid membrane system for the separation of a membrane containing RH should have a high pH value in the feed phase and a low one in the stripping phase should be there.

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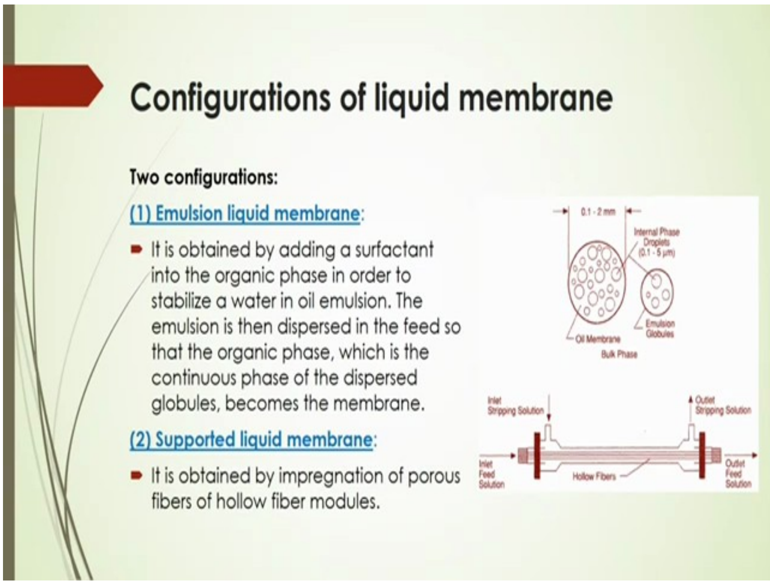

And there are also two types of configuration of this liquid membrane like it is called emulsion liquid membrane, it is obtained by adding a surfactant into the organic phase in order to stabilize water in oil emulsion and also this emulsion is then dispersed in the feed so that the organic phase which is continuous phase of the dispersed like globules that becomes the membrane as shown in figure here.

Another is supported liquid membrane, it is obtained by impregnation of porous fibers of hollow fibre modules there. Now what is the advantage of that liquid membrane? So this liquid membrane is important. Main advantages of conventional solvent extraction in that case by contacting the three phases simultaneously, the solute partition coefficient between the two aqueous phases may be several orders of magnitude that is greater than the one that can be obtained with conventional solvent extraction.

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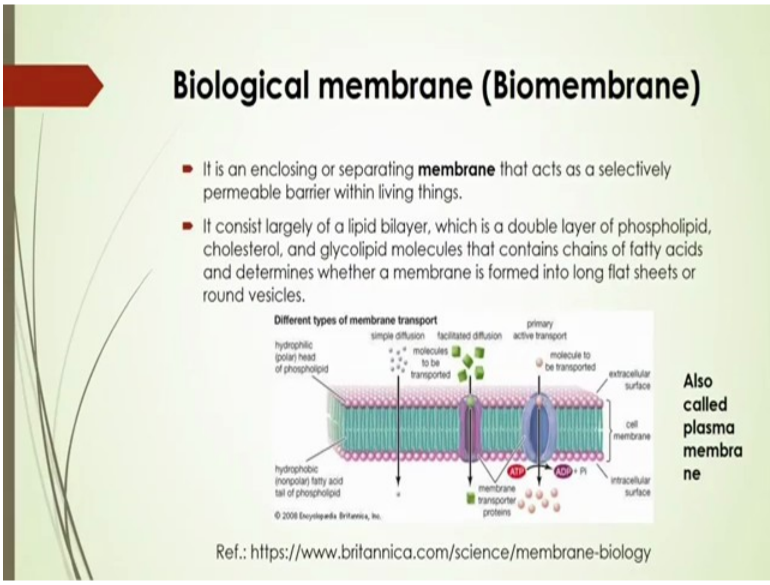

Another type of membrane it is called Bio-membrane. It is also interesting, it is generally consist largely of a lipid bilayer which is a double layer of phospholipid, cholesterol and glycolytic molecules that contains chains of fatty acids and also it determines whether a membrane is formed into long flat sheets or round vesicles and it is an enclosing or separating membrane that acts as a selectively permeable barrier within living things. It is also called plasma membrane.

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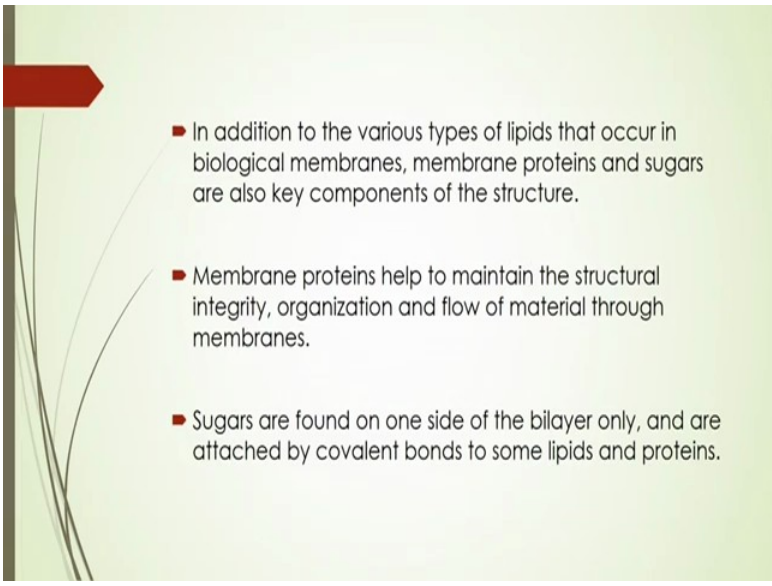

In addition to that various types of lipids that occurred in biological membranes, dismembering proteins and sugars are also key components of the structure and membrane proteins helps to maintain the structure and also the organization and also flow of the material through the membranes. In this case sugars are found on one side of the bilayer only and are attached by covalent bonds to some lipids and proteins.

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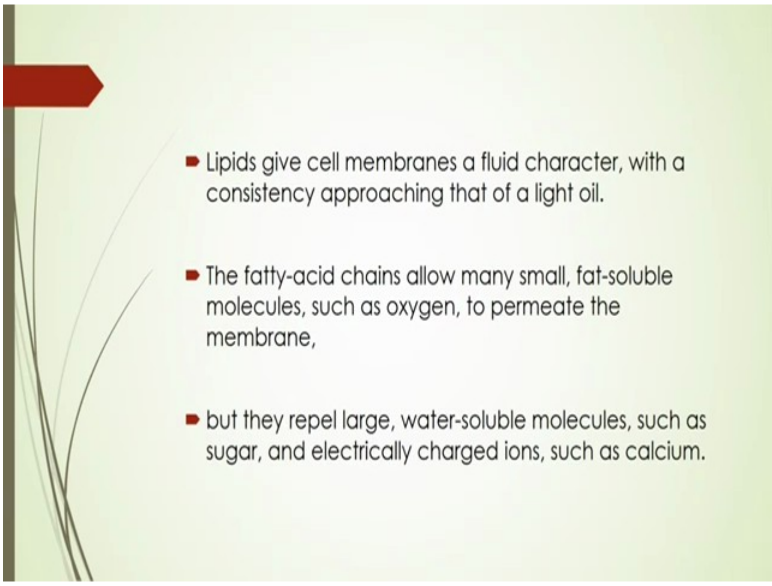

And lipids that give cell membranes of fluid character with a consistency approaching that of a light oil and in this case one application you can say that fatty acids chains allow many small fat-soluble molecules such as oxygen to permeate the membrane.

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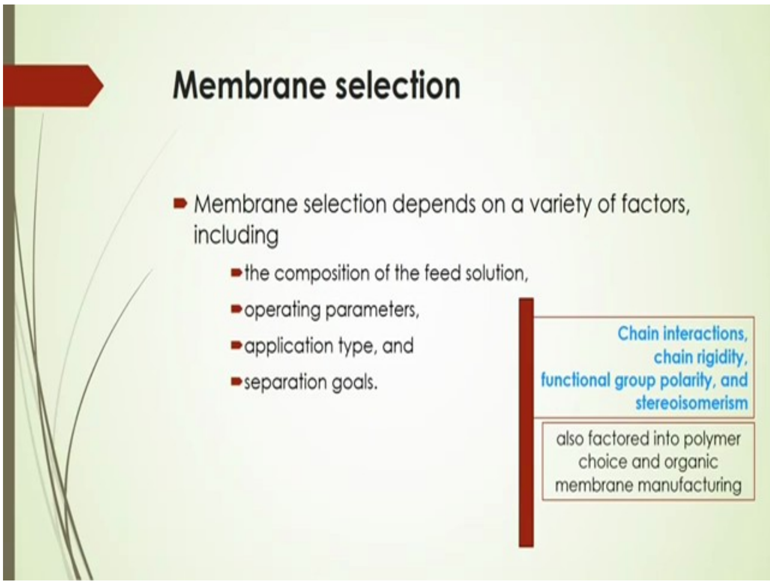

Now there are several different types of membranes, how to actually select that membrane? It can be actually based on several factors like the composition of the feed solution, even operating parameters, application type and the separation goals. In that case chain interactions, chain rigidity, functional group polarity and you can say that stereoisomerism also factored into polymers choice and organic membrane manufacturing system.

So in this lecture we have discussed that several aspects of the membrane. What is the definition of that membranes? How it can be procured? What are the different configurations? What are the material generally being used for procured this membrane and what are the applications of that membrane? And we suspect this intensification will be there, so in the next lecture we will try to discuss more about that engineering of that membrane which is being used for the process intensification.

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So I will suggest you to go through these books for the information more about this membrane and its separation processes and it will be helpful for getting more information about the membrane for the process intensification and its direction to future research thank you.