Mass Transfer Operations II
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Lecture 18 - Membrane Separation Technology

Welcome back to Mass Transfer Operations II course and now we will be discussing on membrane separation technology.

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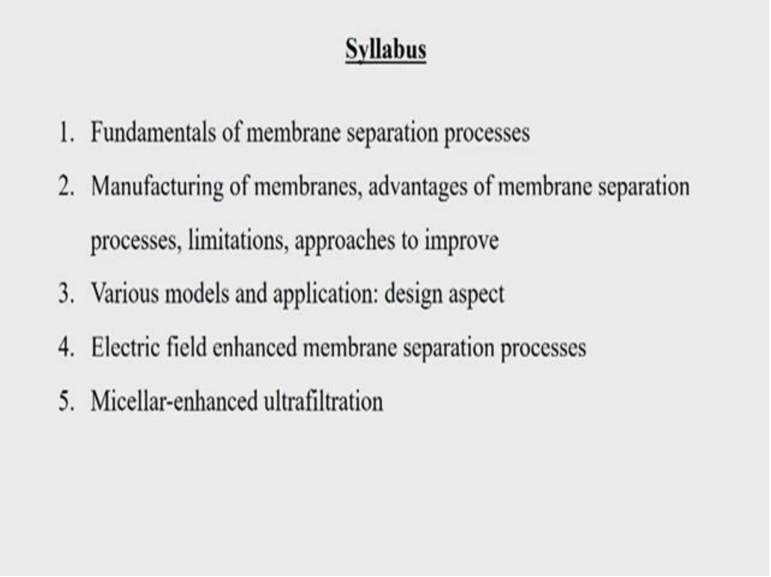

The syllabus is as follows: First I will be discussing on fundamentals of membrane separation processes. Then we will be discussing on manufacturing of membranes, advantages of membrane separation processes, limitations of the membrane separation processes and approaches to improve the membrane performance. The third topic is various models and application in design aspect.

Then we will be discussing on electric field enhanced membrane separation processes. Finally, we will be discussing on the Micellar-enhanced ultrafiltration that is MEUF.

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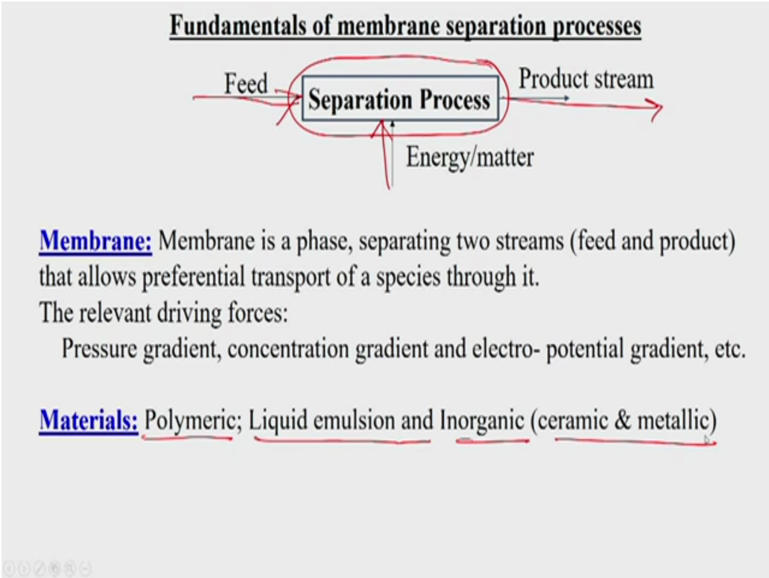

So we will be discussing the fundamentals of the membrane separation processes. How this membrane separation process is different from other separation processes, we need to understand first. Suppose the schematic of any separation process is like that. Say this is the separation process then we will supply feed and energy or matter actually is required to separate something from the feed and then we will getting the product stream.

So this product stream may be of, say we can say permeate maybe of retained in case of membrane separation processes. So first of all, we need to understand the definition of membrane that is, say we can say it is a phase separating two streams, feed and product that allows preferential transport of a species through it. So it can be regarded as the, we can say the semi-permeable barrier.

Or it will allow one particular component to be retained and the other component to be permeating through this barrier, okay. So this barrier may be solid may be liquid, okay and for that we need this relevant driving force as we can say pressure gradient maybe temperature gradient maybe concentration gradient or maybe electro potential gradient, okay. The common materials for the membranes are like polymeric then liquid emulsion then inorganic, so we can say ceramic and metallic membranes, okay.

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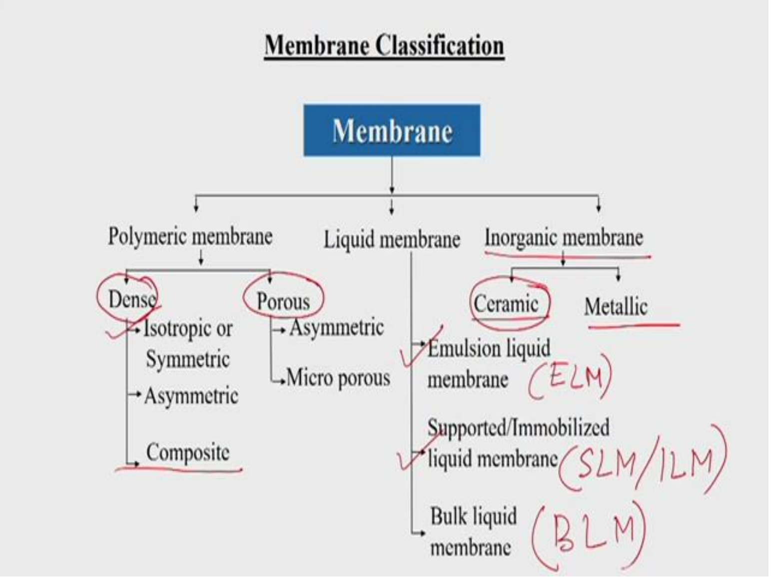

So we will be classifying the membrane in the beginning actually this means one major part is polymeric membrane than we have liquid membrane and the third category is inorganic membrane. So in polymeric membranes we have two different types of membranes like one is this dense membrane and another is porous membrane, okay. In case of the dense membrane we can say this maybe it is isentropic or symmetric or maybe asymmetric also.

And another type of dense membrane that is composite membrane, okay. In case of the porous membrane, that may be isotropic or may be microporous. In most of the cases we can say whenever we will be discussing details about the membrane separation processes we will find that say in dense membrane systems, so we have say reverse osmosis membrane then nano-filtration membranes and most of the industrially available membranes are asymmetric type, that is we can say we will be discussing in details later on.

But whenever we will be talking about say microfiltration membrane or ultrafiltration membranes, these are regarded as the porous polymeric membranes. And another type of membrane that is liquid membrane these are of three types, so one is this emulsion liquid membrane, we can say this one ELM and another is supported liquid membrane SLM or we can say this only immobilized liquid membrane ILM. And the third one is this bulk liquid membrane, okay.

So these 3 different types of liquid membranes are available but most of the liquid membranes are not used industrially, this is we can say in the form of these…lab scale studies. And the third type of membrane that is we can say this one inorganic membrane.

There we have ceramic membrane as well as the metallic membrane. Out of the ceramic and metallic membranes, ceramic membrane is widely used for so many applications and the ceramic membrane has the advantages over the other 2 types of membranes like polymeric membranes and liquid membranes. We will be discussing also in detail after that.

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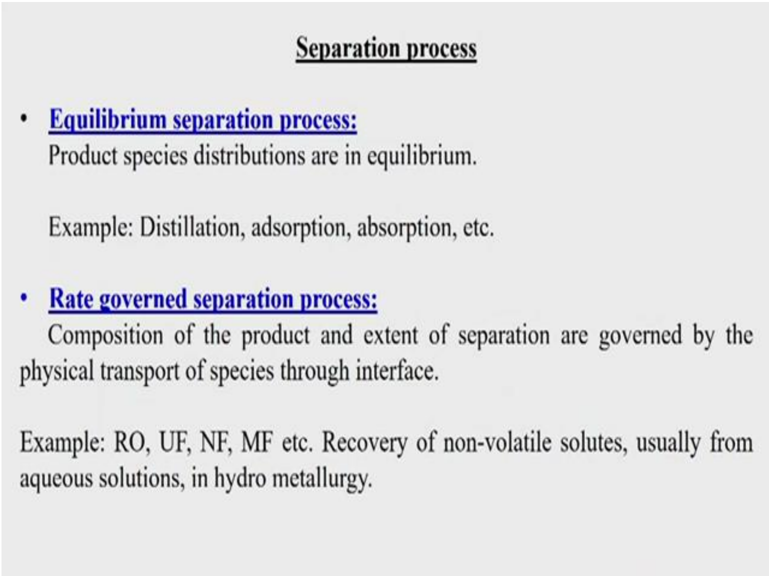

So whenever we will be talking about the separation processes we have these 2 different types of separation processes, one is this equilibrium separation process and another is the rate governed separation processes. So whenever we will be discussing about the equilibrium separation processes that product species distribution are in equilibrium and degree of separation is controlled by the equilibrium.

When a system reaches its equilibrium then the separation process stops and as we know that as per the Le Chatelier's principle if we want to get this reaction to be in the forward direction, then we need to take out the product from the product side and then only we can say this equilibrium will be shifted toward the right hand side and then we can say the process will be in the non-equilibrium condition, then we will get the desired separation or we can get the separation.

So many examples are there in case of this equilibrium separation processes like say distillation then adsorption, absorption, say ion exchange and so many, crystallization, so many processes are there which are, the separation is governed by the equilibrium and another category of the separation process that is we can say rate governed separation process. That composition of the product and extent of separation are governed by the physical transport of the species through the interface.

Whatever the interface actually we are discussing here that is nothing but the membrane. So that we can say the semi-permeable barrier we talk this one as the semi-permeable barrier because it allows one component to pass through this barrier and restricting the one component, this one through that, okay. The examples are like reverse osmosis, ultrafiltration, nano-filtration then microfiltration etc. Recovery of nonvolatile solutes then we can say usually from this aqueous solutions in hydro metallurgy in so many places, we will be discussing the application of membrane separation process in so many industries and so many places.

So there whenever we will be talking about the membrane based separation processes we will find that the separation or we can say this one extent of separation these will be controlled by we can say either this pressure gradient or concentration gradient or electrochemical potential gradient and the size of this molecule to be separated by this semi-permeable barrier, okay.

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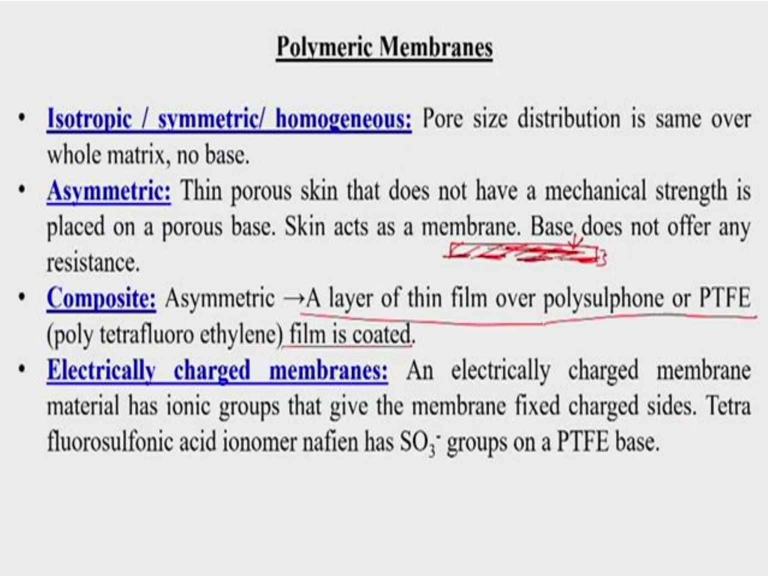

Now we will be discussing about the details of the polymeric membranes say maybe isotropic, symmetric or homogeneous whatever we say this one. So poor size distribution is same over this whole matrix and there is no base. Whatever the matrix is there that is we can say poor size distribution is same but you see in reality the getting symmetric or isotropic or homogeneous membrane is very tough, so generally we get other membranes which are not isotropic or not symmetric or not homogeneous, okay.

Like Asymmetrical membrane, that thin porous skin that does not have a mechanical strength is placed on a porous base like this. Skin acts as a membrane. Base does not offer any resistance. So base actually is highly porous like this if we say so this is the base and then over this one skin actually is replaced here. Then whenever this material actually will pass through this one only the resistance will be offered by this membrane material, not this we can support, okay.

Support is highly porous. In general, these are in the micron or we can say this one in the millimeter, pore size of the base is sometimes in the millimeter range also. Then composite membrane that is we can say this one layer of thin film over polysulphone or PTFE film is coated. So we can see this in composite membrane sometimes we have 2-3 layers of the polymeric films then it forms this composite but in most of the cases we will be getting the asymmetric membrane.

Because you see this one, whenever we will be placing the few layers one after another then the pore size distribution and porosity will not remain uniform, okay. And the one advantage of using this composite membrane is that it is highly stable in any harsh condition. And another type of membrane that is we can say this electrically charged membrane, so an electrically charged membrane material as ionic groups that gives the membrane fixed charged sides.

So like tetra fluorosulphonic acid ionomer nafion has SO_3^- group on the PTFE base. So whenever we have electrically charged membrane then we will be able to separate this charged particle, we can say this one with the high selectivity, okay.

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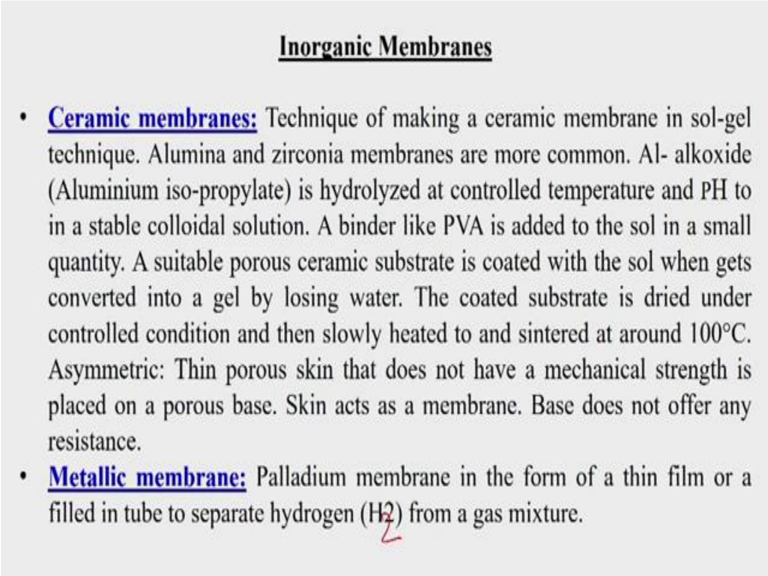

So in case of these inorganic membranes, so we have these 2 different types of membrane, one is the ceramic membrane another is the metallic membranes. In case of the ceramic membranes technique of making a ceramic membrane in sol-gel technique like this alumina and zirconia membranes are more common. Alumina alkoxide is hydrolyzed at controlled temperature and pH to stable colloidal solution. A binder like PVA is added to the Sol in a small quantity. Then a suitable porous ceramic substrate is coated with the Sol when this one gets converted into a gel by losing water.

The coated substrate is dried under control condition and then slowly heated to and sintered at around 100 degrees Celsius. Like in asymmetric ceramic membranes, thin porous skin that does not have mechanical strength is placed on a porous base. Skin acts as a membrane which does not offer any resistance, okay.

We will be discussing also the detailed step-by-step procedure of the ceramic membrane fabrication as well as the polymeric membrane fabrication. In metallic membrane the Palladium membrane in the form of a thin-film or filled in tube to separate say hydrogen is from the from gas mixture that is also available.

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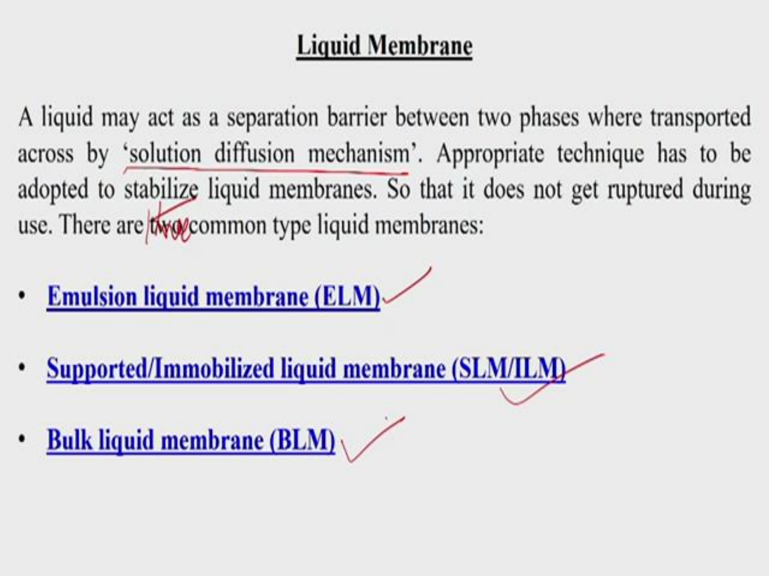

Whenever we will be talking about the liquid membranes, we have these 3 different types of membranes. A liquid may act as a separation barrier between 2 phases when transported across by solution diffusion mechanism. We will be discussing in detail about the solution diffusion mechanism. The appropriate technique has to be adopted to stabilize liquid membranes so that it does not get ruptured during use but you see this one I told earlier also that liquid membranes are not used widely in the industry due to their instability.

But this is used in the lab scale or especially where the solute concentration is very less. In case of these very dilute solutions liquid membranes are effective but that is in the lab scale only. So there are 3 common types of say these three common types of these liquid membranes. One is this emulsion liquid membrane. Another is we can say this one supported or immobilized liquid membranes and third one is this bulk liquid membrane, okay.

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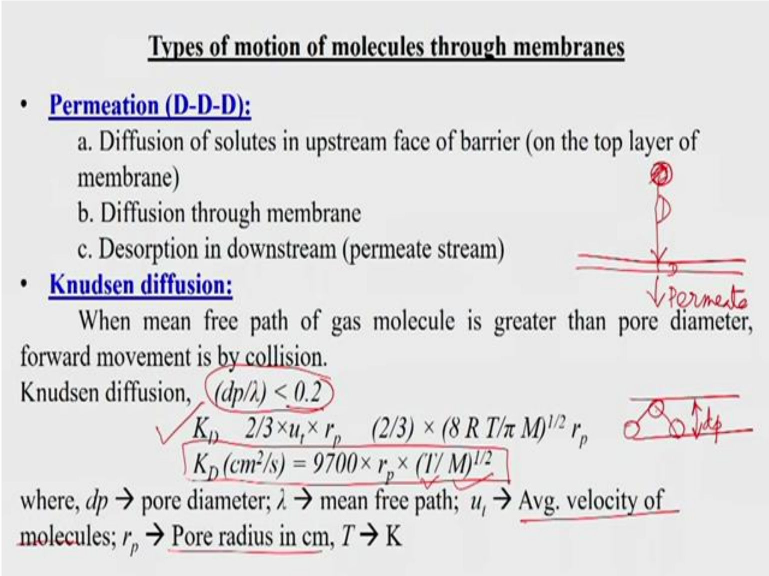

Now we will be discussing about the types of motion of the molecules through the membranes. One type of this one motion of the target component or we can say this one molecule through the membrane is called permeation that we say DDD mechanism. So, first D stands for the diffusion of the solutes in upstream face of the barrier on the top layer of the membrane.

If we say this is the membrane barrier then one molecule actually will be transporting then it will be diffusing from the bulk to the membrane surface. Then the second step will be this diffusion of the solute particle through this the target component or we can say this molecule through this one. So first is D this one then we can say this one, diffusion through the membrane and then third D is the dissolution in the downstream or we can say this one permeate side or this is we can say this one, permeation, okay.

Then another molecule movement is called this Knudsen diffusion, we know this one. When mean free path of the gas molecule is greater than pore diameter then forward movement is done by collision. Suppose we have one pore and one particular target component actually is moving and this mean free path is greater than the diameter like this. Whenever it will be moving to the next position before that it will collide with the wall of this pore.

Then we can say this one, it will, then this forward movement is actually is controlled by this Knudsen diffusivity. This is we can say there is something different from the molecular diffusivity like this. So in that case we can say this one according to this Knudsen diffusivity when dp by lambda is less than 0.2 or we can say this one pore diameter by mean free path the ratio is less than 0.2 then we can say this one Knudsen diffusivity KD is equal to two-third of this u t into r p where u t actually is the average velocity of the molecules and say r p is equal to we can say pore radius in centimeter or in any unit actually. r p means pore radius means through which actually it is moving.

So this is d p. So pore radius is half of this d p and into 8 RT by pi into M to the power 0.5 into r p. So in general we can say this one KD actually in centimeter square per second is 9700 into r p into T by M to the power half just by simplification we will be getting, so where T is the temperature and M is the modular weight, okay. So we can say this one, as per the Knudsen diffusivity the movement of this target molecule through this porous membrane is controlled by Knudsen diffusivity.

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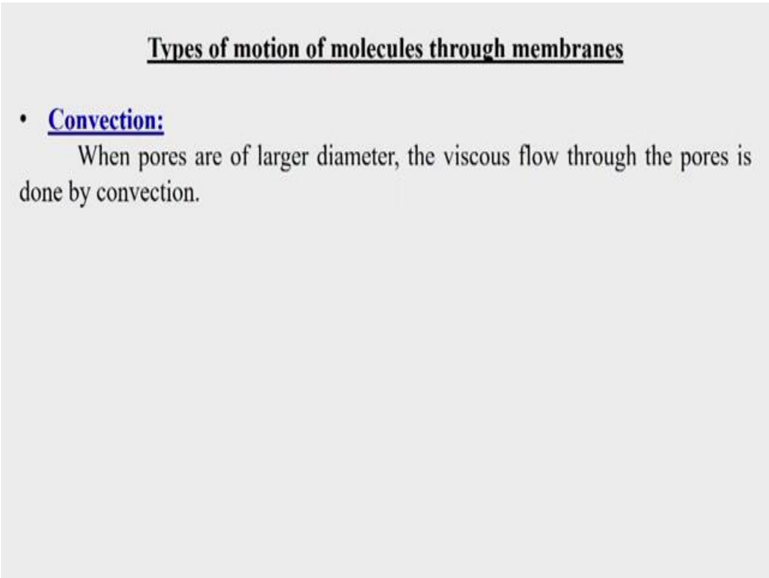

And then third type is convection when these pores of larger diameter then viscous flow through the pores are done by the convection. It is simply we can say this one whenever we will be increasing the pressure then these target molecules will be passing through this one due to only simple convection, okay.

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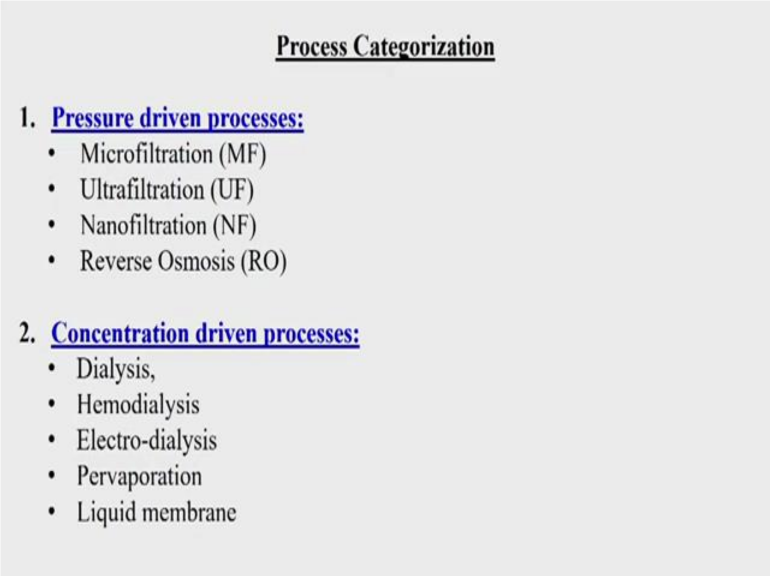

Now we need to do the process categorization. So as per the pressure driven processes we have this for different types of membrane separation processes. One is the microfiltration membrane then second one is this ultrafiltration membrane, third one is this nano-filtration membrane, fourth one is reverse osmosis membrane. And in terms of concentration driven processes we have this dialysis, hemodialysis, electro-dialysis, Pervaporation and liquid membranes.

We will be discussing briefly all these processes because after that also whenever we will be discussing about the different models there we will be discussing in detail but in brief actually we will be discussing all these.

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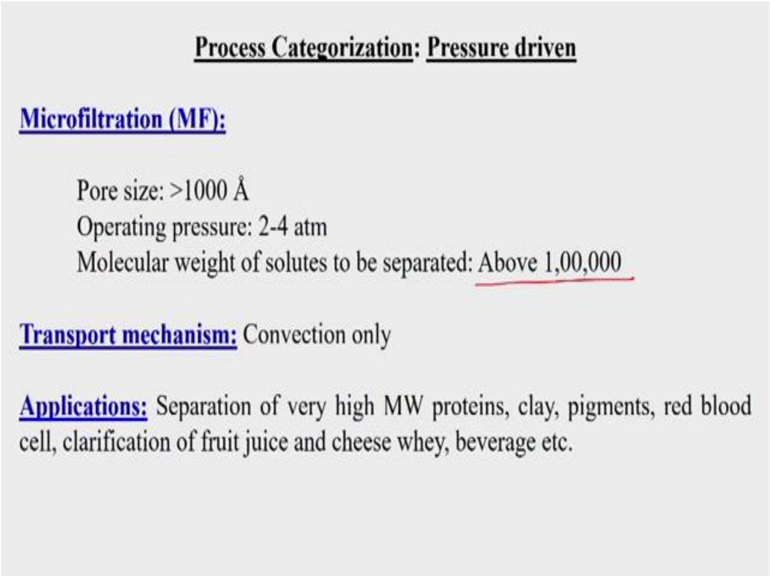

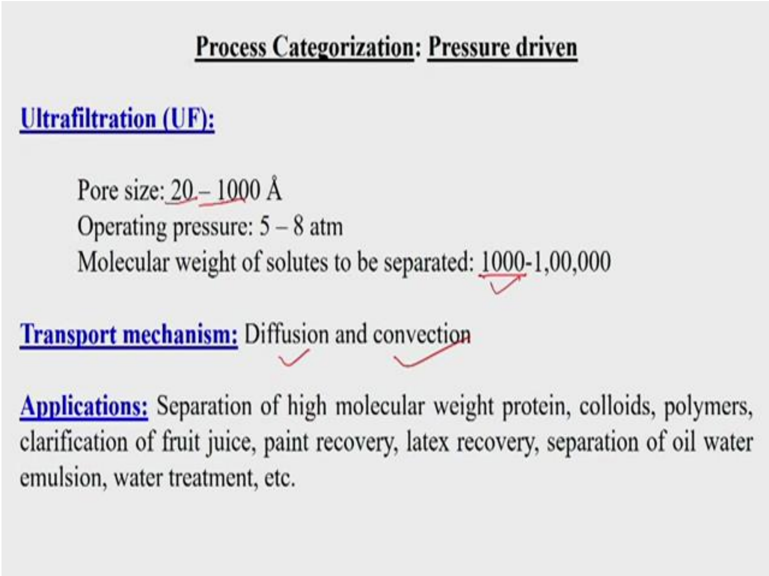

So like microfiltration membrane pore size is greater than 1000 Armstrong and operating pressure is in the low range we can say this one 2 do 4 atmospheric pressure is required to separate the solute particles because in case of the microfiltration the molecules with molecular weight more than 1 lakh is separated by this microfiltration membrane and as the pore sizes are large, that is why we can say this less amount of operating pressure is sufficient to pass the solvent through this.

Then transport mechanism definitely will be convection only. As we are increasing the pressure, the solvent which will be passing and then the solutes with high molecular weight like we can say protein, peptic materials will be retained by the microfiltration membranes.

There are so many applications especially we can say this, in case of this fruit juice clarification like separation of very high molecular weight proteins, clays, pigments then red blood cell, then clarification of fruit juice and cheese whey, beverages and so many applications are there for the microfiltration membrane.

Then ultrafiltration membrane the pore size ranges from 20 to 1000 Armstrong. So we can say this one in case of the ultrafiltration membrane, the pore size is denser than microfiltration membrane. As the pore sizes are denser than micro-filtration membrane that is why the operating pressure range actually is to some extent higher than the microfiltration process.

In that case the operating pressure ranges from 5 to 8 atmosphere and molecular weight of the solutes to be separated like 1000 to 1 lakh, okay. Transport mechanism will be diffusion as well as this convection. When we have these high pore sizes towards this 1,000 then this convection will be taking place. When the pore sizes will be around, so we can say around 20 Armstrong or we can say this one when the molecules with molecular weight around 1000 or more then we can say this one diffusion will take place.

When the molecules in molecular weight in between then these two will be controlling that we can say diffusion as well as this convection will be controlling the transport mechanism. There are also so many applications and we can say this one ultrafiltration has the maximum application in the industry. So separation of high molecular weight protein, colloids, polymers, clarification of fruit juice, then paint recovery, latex recovery, then suppression of oil this one from oily waste water then water treatment, waste water treatment and so many, okay.

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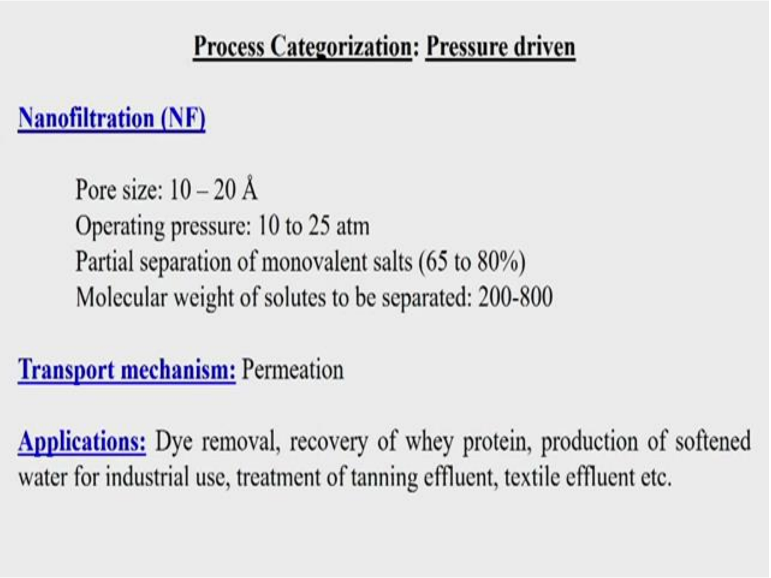

Now we will be discussing about the Nanofiltration membrane. Their pore size now become more denser say only 10 to 20 Armstrong the pore size, means in the Nanofiltration range and then operating pressure is now higher than ultrafiltration membrane. So that is why 10 to 25 atmospheric pressure require, organic pressure gradient is required and then partial separation of we can say monovalent salts also are there, means about 65 to 80 percent monovalent salts are separated by Nanofiltration membranes.

And molecular weight of the solutes to be separated that is in narrow range, we can say this is 200 to 800 molecular weight, the solutes are separated. Mechanism will be permeation only. The applications are like dye removal, then recovery of whey protein, production of softened water for industrial use, then treatment of tanning effluent, textile effluent and so many industrial wastewater treatments are available.

But in terms of operating pressure as it is in higher range that why we can say this one operating cost is to some extent higher than both microfiltration and ultrafiltration process.

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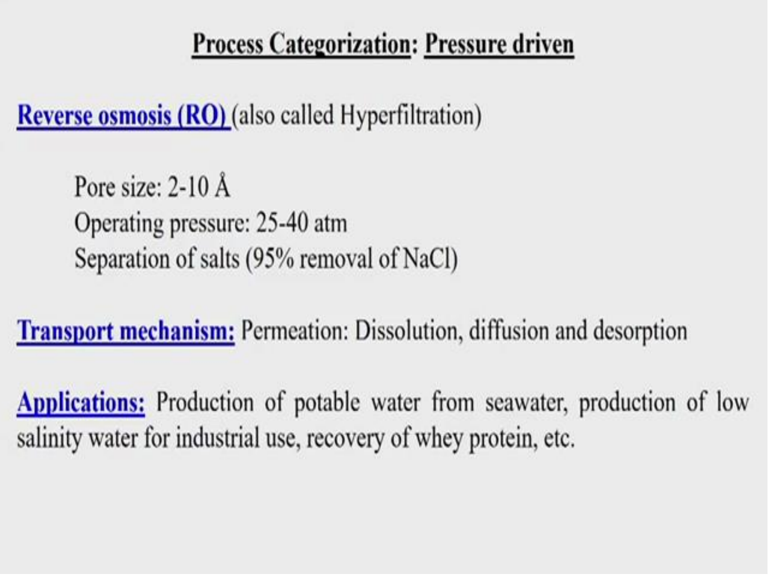

Now the last process we say reverse osmosis process, this is also called hyper filtration, pore size is 2 to 10 and strong but we generally tell this is non-porous membrane or we can say this one highly dense membrane, then operating pressure is very high, so we can say 25 to 40 atmospheric pressure is required for conducting this reverse osmosis process and here we can say this one almost 95 percent of the NaCl is removed by reverse osmosis membrane and transport mechanism will be like permeation that is dissolution, diffusion and desorption only.

The applications are like production of potable water from seawater especially in the Gulf countries where only this saline water is available. For the production of this drinking water the reverse osmosis is used. And production of low salinity water for industrial use, then recovery of whey proteins and so many other applications are there. And reverse osmosis most of the solutes are retained but due to this high operating pressure the operating cost is to some extent high.

And to withstand at this high operating pressure the best material also should be very strong enough to withstand at that high pressure condition, okay.

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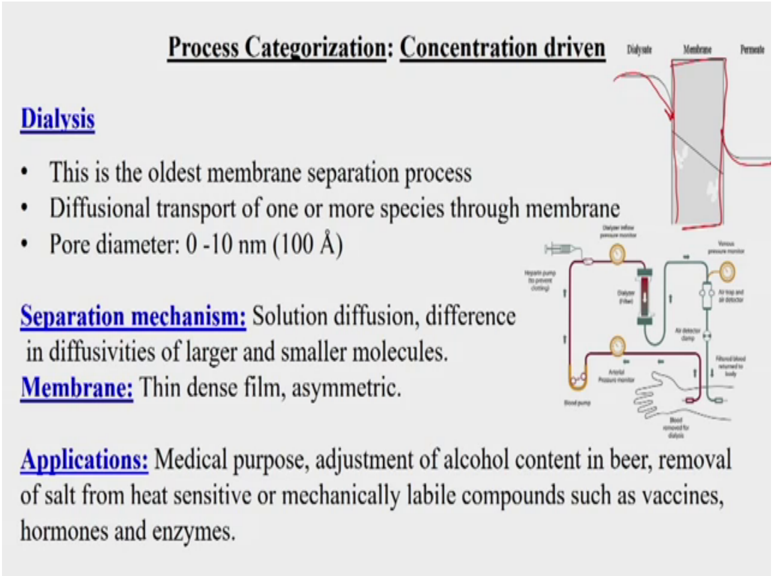

Now in case of this concentration driven processes, first process is we can say this one dialysis. This is the oldest membrane separation process. Diffusion transport of one or more species through the membrane takes place. Like this if you say this is the membrane, say dialyzer actually is supplied here and then we can say the solutes will be retained on the membrane and then permeate actually will be coming out from the membrane. That permeate will be used we can say for the patients like this. Whenever we will be talking about dialysis of the kidney then the permeate with the low salt content will be retained to this patient.

And diffusional transport of one or more species through the membrane takes place and pore diameter actually that is in between we can say reverse osmosis nano-filtration membranes like this. So the pore diameter ranges from 0 to 10 nanometer like this up 1000 Armstrong. The separation mechanism is like this solution diffusion mechanism and difference in diffusivities of the larger and smaller molecules.

And thin dense film asymmetric membranes are used, okay. Main application of this dialysis is that in case of this kidney dialysis that is in the medical purpose and other applications like this adjustment of the alcohol content in beer, removal of salt from this heat sensitive or mechanically labile compounds such as vaccines, then hormones and enzymes, okay.

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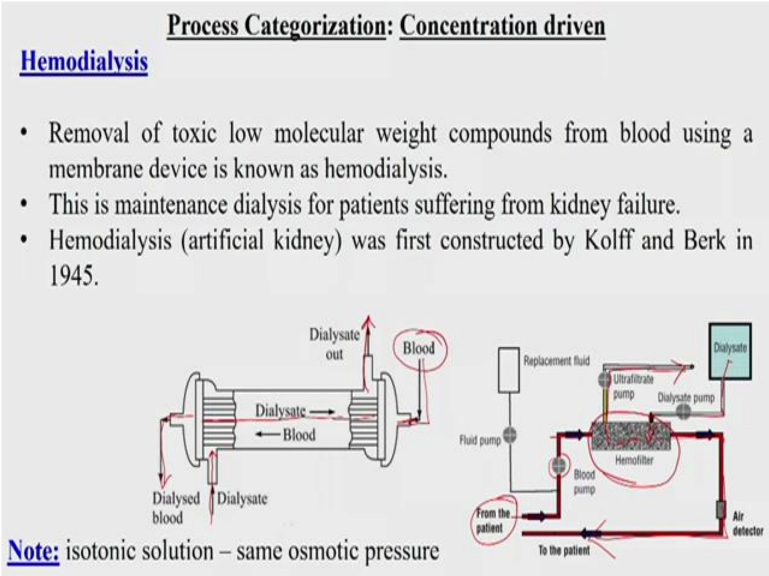

Then the other process that is we can say this concentration driven membrane separation process that is hemodialysis, we know this one the using this hemodialysis we can say the toxic low molecular weight compounds are removed from the blood using a membrane device known as hemodialysis. So the schematic of the hemodialysis is like this. This is similar to that of we can say shell-and-tube heat exchanger like this.

Say from the shell side the dialyzer actually is flown and then dialyzer will be out from the other part of the shell side. And suppose this contaminated blood will be entering through this tube side and then it will pass through this we can say this one through the tubes and it will be dialyzed blood or purified blood actually will be coming out from the hemodialyzer. Okay, so this schematic also of the hemodialysis for this purification of the blood is shown in this figure.

So from the patients suppose the contaminated blood actually is taken and then through this blood pump it enters into the hemodialyzer or say hemo-filter and then dialyzer is actually entered from the we can say this one outside and it enters into the hemodialyzer and then using this ultra-filtrate pump actually that what is called that the exhausted dialyzer actually is thrown away and the purified blood is, we can say this one, is again fed to this patient through this, we can say this one, booster pump, okay.

We will be discussing this one. So this is we can say this one maintenance dialysis for patients suffering from kidney failure and hemodialysis we can say this one as artificial kidney was first constructed by Kolff and Berk in 1945 and we need to remember here that in case of this hemodialysis we need to make this isotonic solution which is same osmotic pressure with blood. Means whenever we will be putting this dialyzer that we need to say what is this we can say osmotic pressure.

Otherwise the blood will come into the dialyzer and then or the reverse may happen also. Means dialyzer will enter into the blood and it will clot this blood and then it will create the hazard to the patient.

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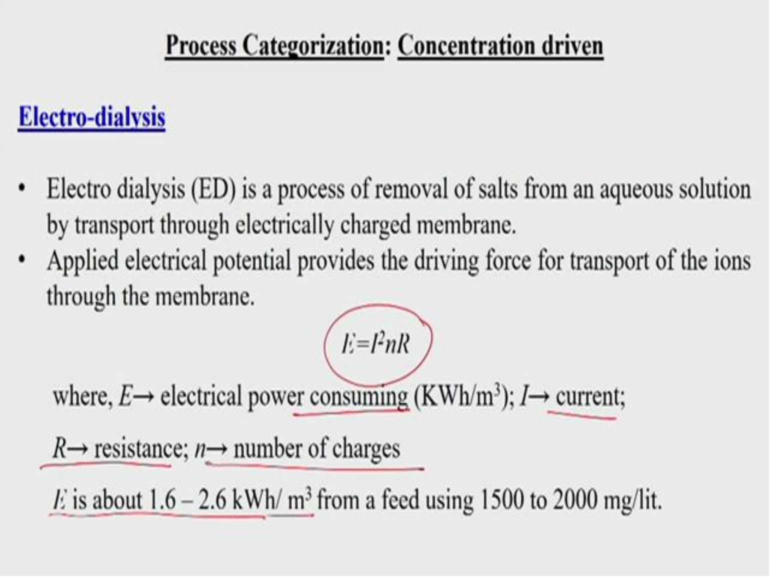

Then another concentration driven membrane separation process is called electro dialysis. So electro dialysis is a process of removal of the salts from an aqueous solution by transport through the electrically charged membrane. So applied electrical potential provides the driving force here for the transport of the ions through the membrane where E is equal to I square into n R where E is the electrical power consuming and then I is the current and then R is the resistance and n is the number of charges.

And E is about we can say this one, 1.6 to 2.6 kilowatt hour per meter cube from a feed using 1500 to 2000 milligram per liter.

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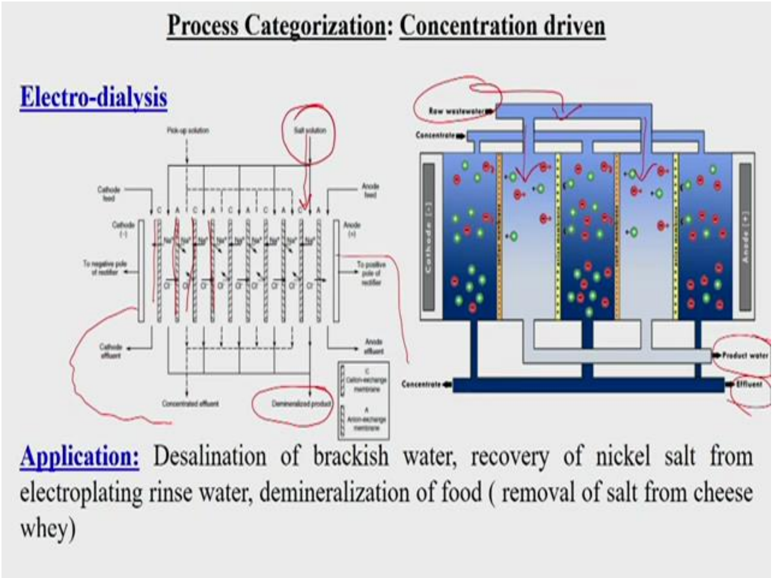

The schematic actually of the electro dialysis is that say we have these so many cathodes and anodes, these are say cathode, this is anode, so cathodes and anodes are placed we can say this one alternatively and then we can say feed is actually fed from this, suppose the salt solution is supplied in all the chambers and then say cathode and anodes are actually linked with this power supply like this cathode and anode.

And then we can say this one whenever the charged materials are there, then as per their opposite charges the salts or we can say this one ions will be attracted towards the cathodes or anodes and then we will be getting this demineralized product from the different chambers of the electrodialyzer. Here also the same thing is drawn here or we can see this one is shown here. Suppose raw wastewater actually is fed from this top with this distributor, like this.

It is coming like this with the different, suppose in alternate chambers and then cathode and anodes are connected with this DC power supply and then as the raw wastewater contain some amount of charges, so these opposite charges will be attracted towards we can say cathodic plates and anodic plates and then whenever product water actually will be coming out, that would be free from all the charges, okay.

And then say effluent will be separated from the bottom of these alternate chambers, okay. So applications are like this: desalinization of brackish water then recovery of nickel salt from this electroplating rinse water, then demineralization of food, removal of the salt from cheese whey and so many electrodialysis applications are there.

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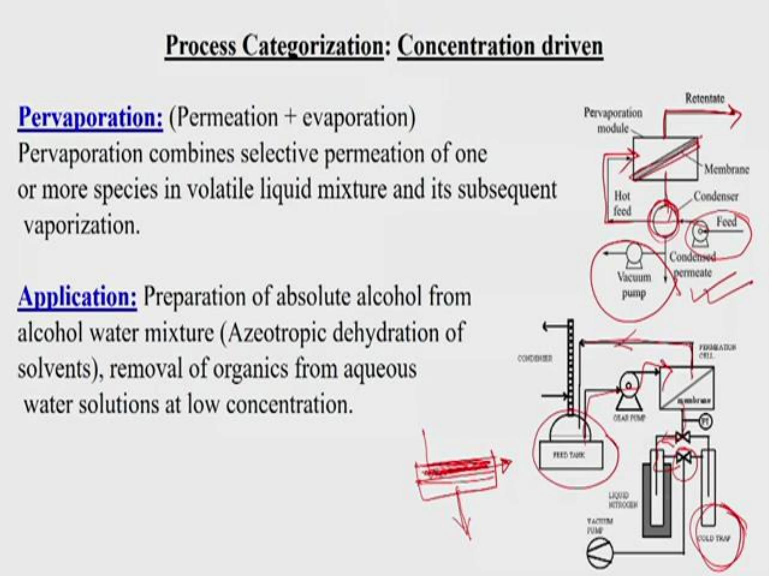

Then another process that is we can say this pervaporation that is nothing but the permeation followed by evaporation. So pervaporation combines the selective permeation of one or more species in volatile liquid mixture and its subsequent vaporization. Like we can say this one, this is the membrane, suppose this is the membrane and say we have this one hot feed, we will be discussing this one in detail.

Suppose this feed is supplied and then it is, by help of this, we can say this one condenser, it is made hot or we can say it is heated and then it is actually fed to this pervaporation chamber. And the opposite side of the membrane say vacuum pump actually is there so that this whatever the hot feed enters, inside this hot feed suppose few components are there which have this low volatility.

So at that condition as the vacuum is created in the opposite side then we can say one or two components will be vaporized and then this will enter through that membrane and that will be collected through this vacuum pump. We can say whenever it will be condensed then we can say this one condensed permeate we will be collecting or we can say this one whatever the more volatile components will be separated and whatever the less volatile component will be retented, okay.

So based on that this one relative volatility, say this pervaporation is affecting. And another point is that using this pervaporation the very dilute solutions also are we can say this one treated or we can say whatever the solutes present in the dilute condition these are also treated with pervaporation. Application of pervaporation like this, preparation of absolute alcohol from this alcohol water mixture.

We can say that is Azeotropic dehydration of the solvent, removal of organics from aqueous water solution at low concentration. So this is we can say this one, one schematic of this system like this, say we have this, suppose we have this feed tank where feed is there and using this gear pump we are putting this into the membrane shell. Suppose this is the membrane shell and then suppose and say membrane, this is the membrane and we are incorporating this feed here and so vacuum is created in the opposite side of the membrane.

So then the high volatile material will be coming out from here and whatever the more volatile component that will be retained there, then it will be collected from the other side of the membrane module, that is why we can say this one part is there what is called permeation shell. Suppose from here one part will be there which is we can say with low volatility or we can say which are with this very volatility or we can say has this low boiling point.

And here you see this vacuum pump is there and say cold trap is also there. Whenever it will be connected in this direction then the components with high volatility or we can say these low boiling materials will be coming through this one and will be collected in the cool trap, okay.

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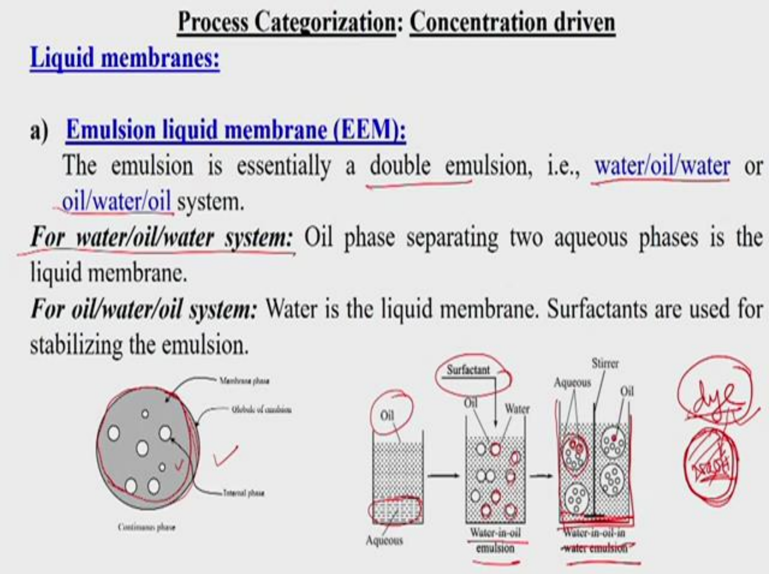

Whenever we will be discussing about the liquid membranes, I already told that this liquid membrane applications are not yet done industrially or we can say due to its instability. So the first type of this liquid membrane that is emulsion liquid membrane in brief it is ELM.

The emulsion is essentially a double emulsion like water, oil, water or oil, water, oil system. For water oil water system oil phase separating 2 aqueous phases is the liquid membrane.

Suppose this is the water oil water globule then this space, we can say this one oil phase will be separating to aqueous phases. Suppose here also aqueous space will be there then these 2 will be separated by this emulsion. For oil water oil system, water is the liquid membrane. So means what will make the film. So like bubble water will make film and then surfactants are used for stabilizing the emulsion and it actually creates the liquid membrane.

Like I said we have this aqueous system and we have oil also then we are adding some amount of surfactant then if we agitate this one then we can say some amount of the, so we can say micelles will be formed like this one. So this is one kind of water in oil emulsion like this and if we agitate more also, sometimes if we agitate more then it will be water in oil in water emulsion.

So in this we can say this one, in this, inside this aqueous again the bubble will be formed and then this aqueous layer actually will be formed and suppose oil will be there inside this. So there we will be getting water in oil in water emulsion, so that type of system also is there. We are making some emulsion using the surfactant in presence of oil, okay that either this film of this oil or the film of water will act as the liquid membrane and this one target component which will be separated using this liquid membrane that will be entrapped inside this emulsion.

Suppose we are trying to trap one say dye from this aqueous solution. Then the aqueous solution will be the feed and inside this feed we will be generating this suppose water oil water emulsion, then oil will make one layer and inside this water which is there that will have some amount of we can say either sodium hydroxide or sulfuric acid or any other thing or gelatin compound which can make the complex with this dye.

So that dye will move through this we can say either oil barrier or water barrier to react with this whatever the component present inside this emulsion or inside this globule, there it will be entering to trap and this one to make the complex. Like this the concentration of the, suppose this is one barrier and outside this one suppose dye is present here and here suppose sodium hydroxide is present.

So suppose this is oil barrier, this is dye is in water and say sodium hydroxide also in water, the concentration of dye will be here high and inside this one it is 0, so due to this concentration gradient this dye will be entering through this emulsion and then it would react with sodium hydroxide to this one to be trapped here and say this one dye will be separated from this aqueous solution to inside this emulsion.

Once it will be bigger in size due to this entrapment of these dyes, so these all the emulsions actually will fall down on this we can say this one in the liquid emulsion system and then these will be collected from the bottom of this container. But one point is that it has a limit, once it will exceed its limit means then the emulsions actually will be broken or so many emulsion will coalesce and then the size will become larger and sometimes these will also brake.

So due to the reaction of some amount of reaction of sodium hydroxide with the oil also, we can say the stability of the film decreases, okay.

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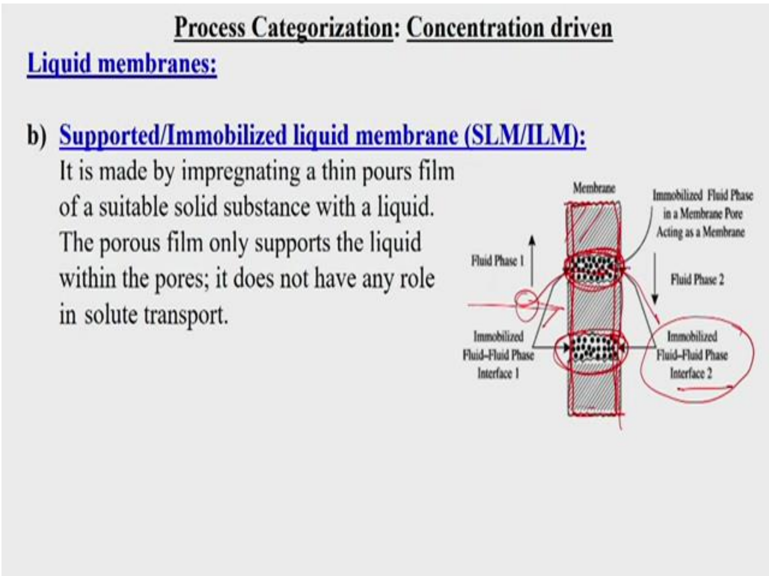

The second type of the liquid membrane that is supported or immobilized liquid membrane. So this is very simple. Suppose this is the actual membrane and inside this membrane so many big-big pores are there, so it is made by impregnating a thin porous film of a suitable solid substance with a liquid. The porous film only supports the liquid within the pores. It does not have any role in the solute transport.

Means suppose this is the supported liquid membrane means this is the membrane and inside this big pores suppose immobilized fluid-fluid phase or interface is there, then when a particular target component is brought into contact with this membrane then this material actually we will be transporting through this immobilized phase and then it will be separated in another side of this membrane, that is we can say this one immobilized fluid-fluid phase, interface 2. Means from the opposite side of this supported liquid membrane. So this is also used in the lab scale for the separation of so many dyes or so many metals, okay.

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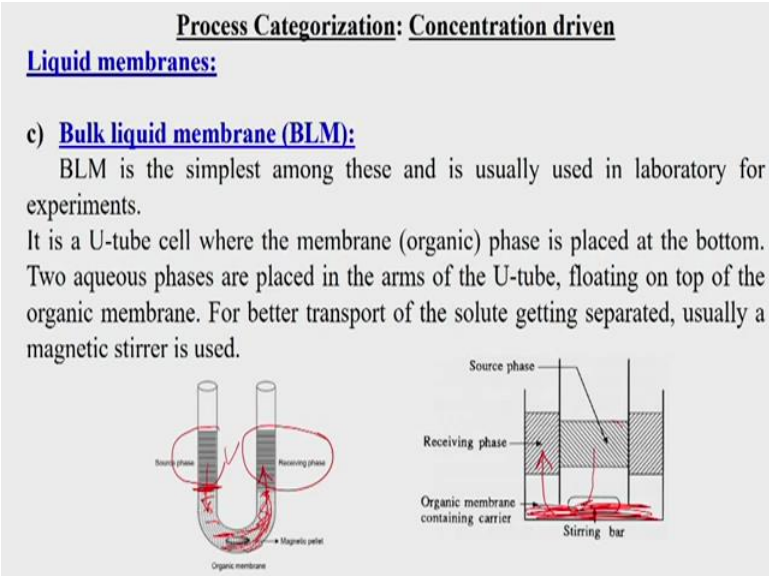

And then third type is this bulk liquid membrane, so BLM is the simplest among these and is usually used in the laboratory for experiments actually. It is one U-shaped cell where the membrane we can say this one membrane is placed here and say at the bottom of this U-tube and the two aqueous phases are placed, suppose one is this we can say this one source phase and in one arm of this U-tube and we can say this one another is the receiving phase and putting on the top of the organic membrane like this.

So here we can say this one in the contact of this we can say this one organic membranes, suppose the target component will be transported from here and then we will be coming to this receiving phase. So here also it is like this, suppose this is the receiving phase and this is a source space like this, here this organic membrane actually replaced and then say from the source space we can say this one target component will be coming to the receiving phase, okay.

For beta transport of the solute getting separated usually a magnetic stirrer is used, suppose this stirrer is used to get the better transport of the target component.

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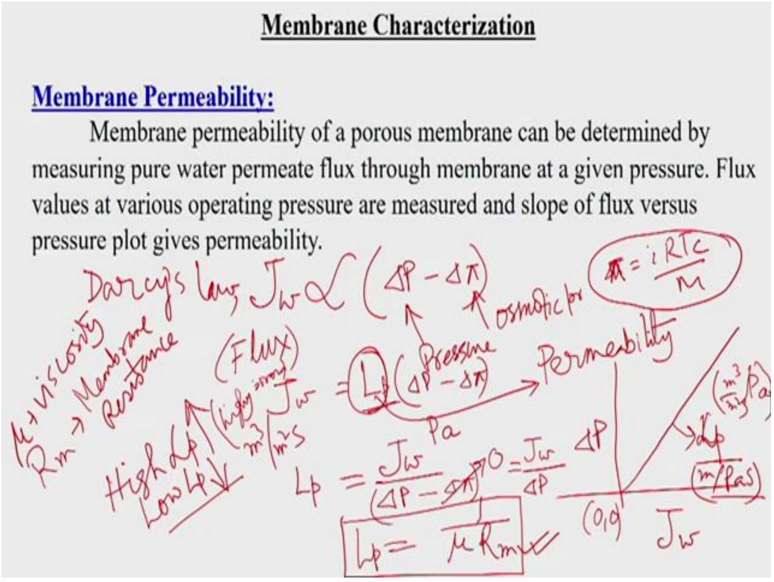

Now we will be describing the membrane characterization. So whenever we will be demanding that or we will be claiming material as the membrane, then we have some guidelines or we can make this one in terms of some characterization parameters. The first parameter is membrane permeability that the permeation ability of the membrane or we can say this one whenever we have one target component how much it can retain or we can say this one whatever the carrier solvent or say solvent will be permeating through this one.

So membrane permeability of the porous membrane can be determined by measuring pure water permeate flux through this membrane at a given pressure. So flux values at various operating pressures are measured and the slope of the flux versus pressure plot gives the permeability. So as per the Darcy’s law actually we will be say, as per the Darcy’s law we can say J w that is we can say water flux is proportional to we can say this one dragging force, del P minus del pi, okay.

So this is actually we can say this one volumetric flux. Whatever permeate actually coming out through this membrane that is we can say pressure gradient, this is osmotic pressure. So we can say this one pressure gradient, this is osmotic pressure. So J w actually we can say this one, J w is equal to, so one constant parameter is there proportionality constant L p, del p minus del pi, okay.

So this L p is called this membrane permeability. So this L p is nothing but we can say the proportionality constant of flux versus driving force, okay. So this is called permeability membrane, hydraulic permeability. So if we plot say del p versus J w, so we will find that this is suppose 0, 0, so if we increase this as per this Darcy’s law, if we increase the driving force, so on the membrane system then permeate flux value will go on increasing because this is linearly proportional.

So we can say if we increase this driving force then we can say flux value will go on increasing, okay. And this slope actually will give L p. So L p is nothing but we can say this flux value is we can say meter cube per meter per square second and then pressure will be suppose this Pascal or kilo Pascal. So the unit of L p will be meter cube per meter square second into Pascal, okay.

Or simply we can say this one meter per Pascal second. So it will be like this meter per Pascal into second. So unit of L p will be meter per Pascal second, okay. And say this one the membrane permeability actually this tells us about the we can say the how porous the membrane is. If we say this high L p means then we can say this one this membrane is highly porous. If we say this very low L p then we can say this one the membrane is less porous.

We can say this one, highly porous. If we say low L p then it is very less porous membrane. So we can say this one the microfiltration membrane has maximum porosity whereas we can say this one reverse osmosis membrane has less porosity, okay. And also this one this L p that is we can say this one is equal to J w that is permeate flux by del p minus del pi. So if we can say this 1 minus del pi but for pure water say del pi will be 0, that is we can say this one will be J w by del p. So that is actually we can say will be equal to 1 by say mu into R m. So L p is equal to 1 by mu into R m, okay.

So where this mu is this we can say this viscosity and R m is the membrane resistance. So that mu is equal to we can say this one is the viscosity, mu is viscosity, viscosity of the permeating solvent and R m is membrane permeability. This is we can say membrane resistance, okay. So that we can get this one, if we know the resistance of the membrane itself because you see membrane is the porous medium, it will offer some resistance and if we know the viscosity of the permeating what is called fluid then L p also we can get from here, okay.

And we know that osmotic pressure delta pi that is equal to say i RTC by m. So in case of this high molecular weight compounds the osmotic pressure is very less and whenever we have this low molecular weight compounds and ionic species, their osmotic pressure value is very high.

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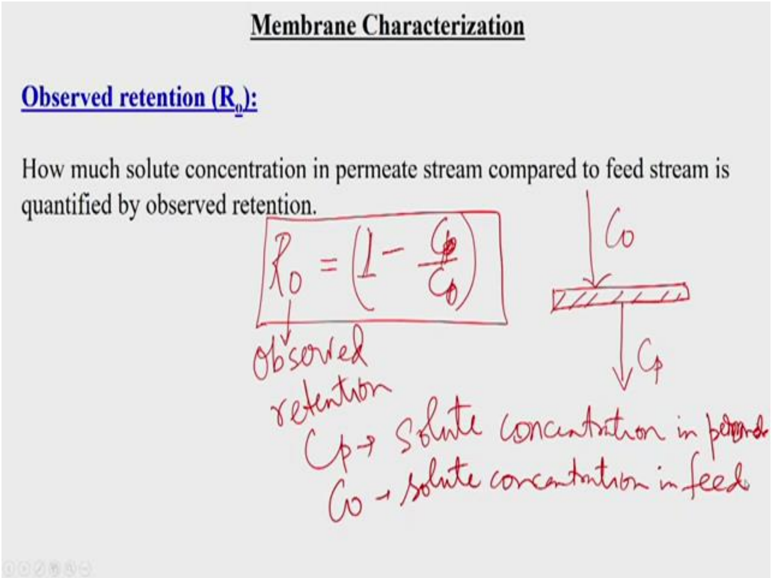

The next characterization is by observed retention. So this is how much solute concentration in the permeate stream compared to the feed stream is quantified by this observed retention, okay. So observed retention actually we can say R o is equal to 1 minus C 0 by C p, sorry C p by C 0. So we can say this observed retention is equal to 1 minus C p by C 0 means if we have this membrane, suppose we have this membrane and solute concentration in the feed side is C 0 and permeate concentration means the concentration of the solute in the permeate side is C p then how much actually is retained means the solute concentration will be retained, that is one minus C p by C 0. That will give this observed retention means that amount is retained by this membrane, okay.

So that is we can say observed retention and C p we can say solute concentration in permeate and C 0 is solute concentration in feed, okay.

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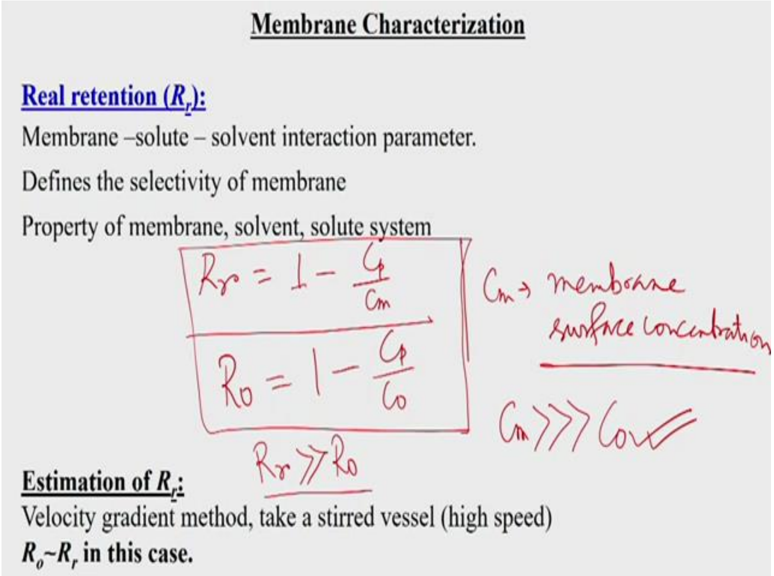

And then the next characterization is real retention but we know that this membrane separation process is a dynamic process and it is not gone by the equilibrium of the system. It indicates that whenever the permeation operation is on then the solute concentration on the feed side will go on increasing, okay. So in the beginning the solute concentration was C 0 but whenever the process will be completed that time the solute concentration will be much higher than C 0.

Because the solvent has passed through the membrane keeping the solutes in the feed side. So we can say this one it is actually we can say the membrane solute solvent interaction parameter. So this defines the selectivity of the membrane or we can say property of membrane, solvent, solute system. Then R r is equal to we can say observed retention is equal to 1 minus C p by C m.

Where we can say this C m, say here actually you see C m is equal to membrane surface concentration. Means it is the maximum concentration of the solute on the membrane surface. So suppose in the beginning the concentration wise C 0 but say when the process is completed that time the solute concentration is increased from C 0 to C m but the C p actually is we can say the permeate concentration.

So now from here we can get that in case of this observed retention that is we explained as 1 minus C p by C 0 and real retention is equal to we can say this one 1 minus C p by C m and we know that C m is much much greater than C 0. So from here we can say that real retention value we can say this is much much will be at least greater than say observed retention. As we can say C m is greater than 1, so we can say this one right-hand side or this second term of this right-hand side will become say lower. That is why it will be say R r will be high.

But we see we can get this one, we can estimate this observed retention, real retention value. The velocity gradient method is there. We need to take stirred vessel with high-speed, there whatever we will be getting this observed retention then that will be this real retention because membrane surface concentration is a fictitious concentration, we cannot measure this one instantly for a particular membrane operation because it is completely dependent on the operating condition, okay.

But initial concentration and whatever the permeate concentration that is we are getting this one, we can from the experiment, okay.

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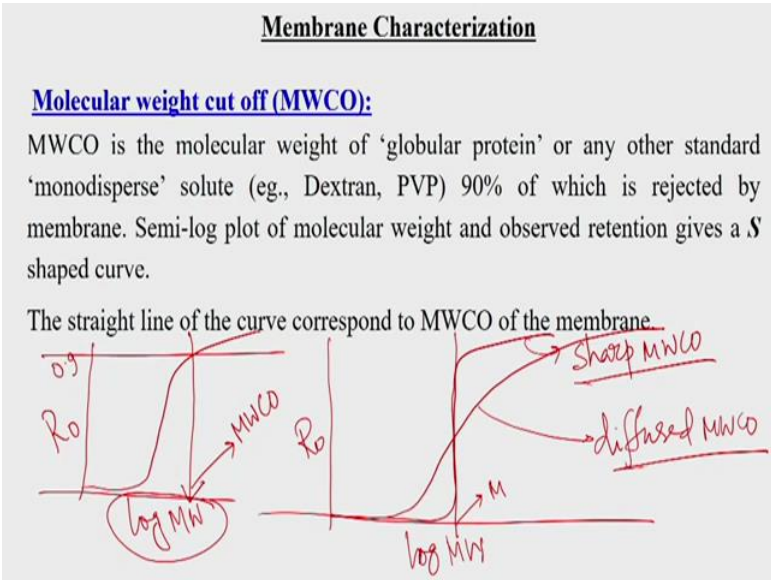

And then another characteristic is this molecular weight cut-off that is MWCO. MWCO is the molar weight of globular protein or any other standard monodisperse solute like dextran, PVP et cetera, 90 percent of which is rejected by the membrane. Like this we can see if we draw one observed retention R o with say log of molecular weight cut-off.

Molecular weight actually log of molecular weight actually if we plot this one, so if we plot this log of molecular weight and R o then we will be getting suppose one graph actually we will be getting like this. Whenever this 90 percent 0.9 actually we will be getting here then a corresponding molecular weight, so we will be getting this log of molecular weight. From there whatever the molecule weight we will be getting that will be MWCO, okay and similar plot of the molecular weight and observed retention gives this a safe curve like this one.

The straight line of the curve correspond to MWCO. The straight line of the curve we can say this. In general we can say this one if we have this sharp molecular cut-off like this, if this is the observed retention versus log of molecular weight then this will correspond to MWCO. So this is we say is sharp MWCO but we say sharp MWCO generation or manufacturing is very tough but in reality most of the membranes are with diffused molecular cut-off like this, so where we can say this one there is no straight path actually in the R o versus log MW part, that is diffused molecular weight cutout.

So in this case, in case of this diffused molecular weight cut-off membrane, so there will be a distribution of the permeate concentration for the entire experimentation or we can say the C p value will be varying actually or we can say this one we will be getting range of this C p values or we can say particular membrane operation, okay.

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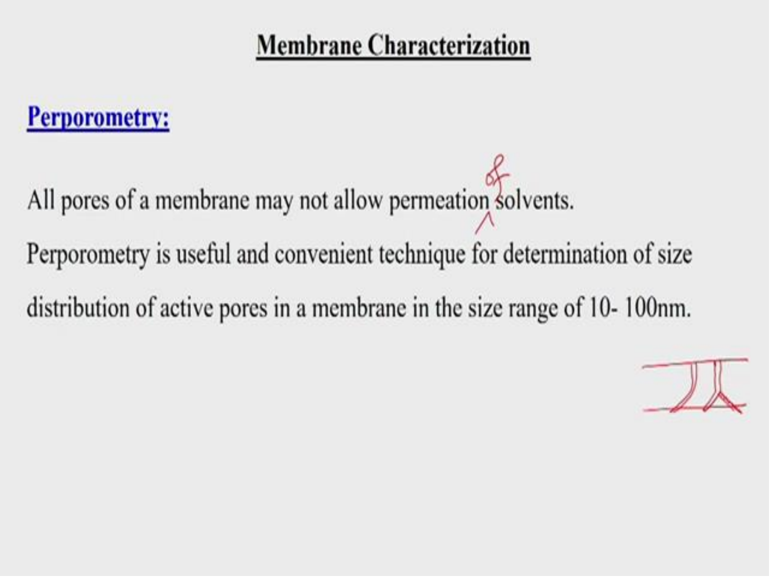

And another characterization is this Perporometry. So all pores of a membrane may not allow permeations of the solvent actually. Maybe some of the pores may be dead. Suppose this is the membrane and then suppose the shape of the pore is like this or sometimes suppose this pore has bifurcated or maybe this part is damaged. Suppose this part is now dead. So maybe so many combinations maybe there, so Perporometry is useful and convenient technique for the determination of the size distribution of active pores in a membrane in the size range of 10 to 100 nanometre. So in this range actually we can say pore size distribution we can get.

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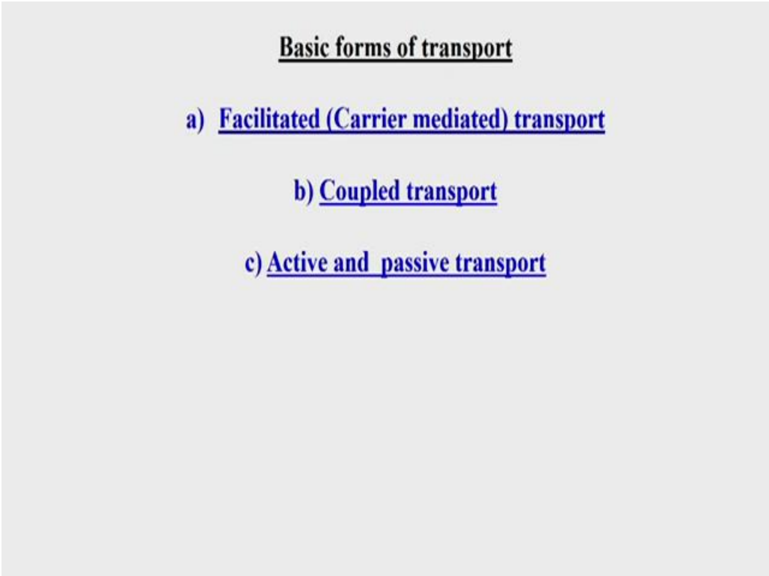

Now these basic forms of the transport. Say one is this facilitated transport that is carrier mediated transport, another one is coupled transport and third one is this active and passive transport through this membrane.

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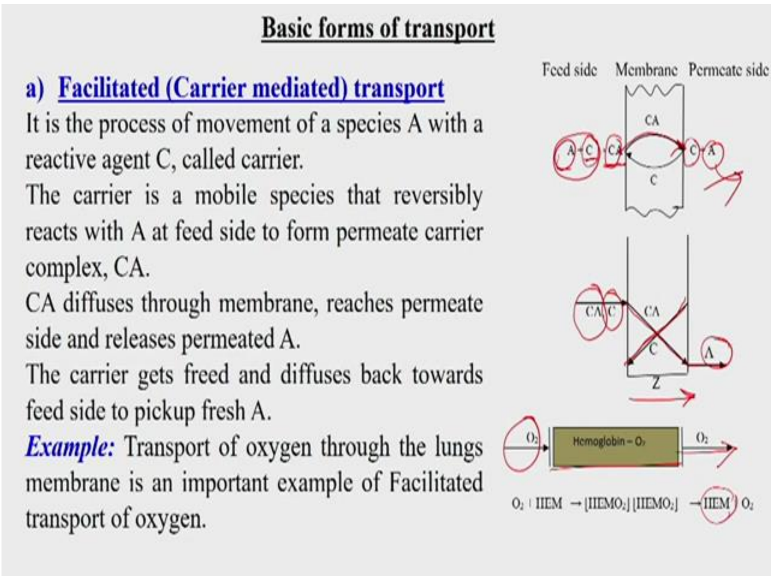

So first one is we can say this one facilitated or carrier mediated transport, this is very simple. It is a process of movement of species A with a reactive agent C that is called the carrier. Suppose A is there, so this is our target component that will be separated using this membrane. And one carrier component is there that is we can say this is C. So now it will be making one complex like C A, okay.

The carrier is a mobile species that reversibly reacts with A at feed side to form permeate carrier complex, C A. So it will be moving from one side of this membrane to the other side and then in the other side actually C will free A then it will be obtaining this one, okay. The C A diffuses through membrane reaches the permeate side and releases the permeated A. So here actually A will be separated.

Like this the concentration of the A is shown here through this Z means across this thickness. Suppose the C A is there because C is the carrier then C A concentration will go on decreasing across this membrane and then here actually we will be getting the A where in other words this concentration of solute actually C will be increasing in this direction. One example of this transport of this oxygen through the lungs membrane is an important example of the facilitated transport of oxygen.

That the oxygen is entering in the, it will be transported through this hemoglobin and then in the lungs actually oxygen will be we can say separated will be discharged and the hemoglobin again will be coming back to the system.

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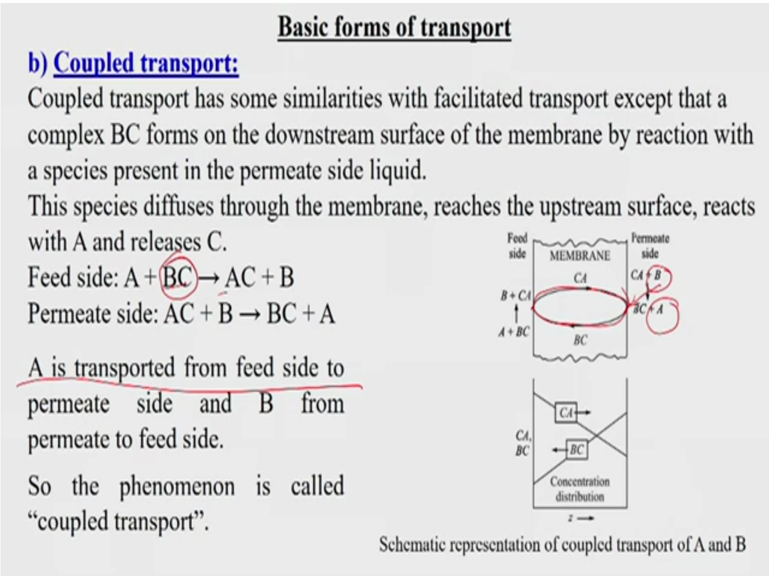

And then second one is the coupled transport. The coupled transport has some similarities with the facilitated transport except that complex BC forms on the downstream surface of the membrane by reaction with the species present in the permeate side liquid. The species defuses through the membrane, reaches the upstream surface and reacts with A and releases C like this.

So this is almost similar to that of the facilitated transport, only here you see this one suppose A is there it will couple with BC and then AC will be transporting from one side to another side and there it will be this one reacting. This will be say in the permeating side, B will be freed and then it will again react with C to make BC. It will be coming back and releasing this A. Like that way, so A is transported from feed side to permeate side and B from permeate to feed side like this. So the phenomena is called coupled transport.

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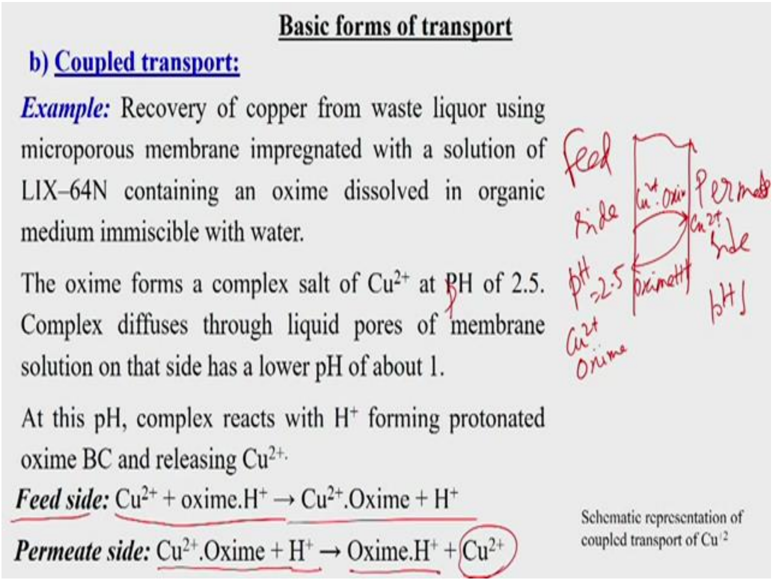

And the last this one basic form of transport that is we can say this one coupled, sorry, this example of this coupled transport is recovery of copper from this waste liquor using this microporous membrane impregnated with a solution of say LIX64N containing an oxime dissolved inorganic medium immiscible with water. The oxime forms a complex salt of copper 2 at PH 2.5. And complex diffuses through liquid pores of membrane solution, on that side has a lower pH of around 1.

So at this pH this complex reacts with H plus forming protonated oxime BC and releasing Cu 2 plus, like this will be like this. Suppose this is the membrane and then suppose this is the feed side. So pH is 2.5 and this is the permeate side. So pH is 1, so copper 2 plus is there and oxime also is there and it will be transporting like this one. Say copper 2 plus oxime complex and then say here actually copper 2 will be separated and then only oxime will be coming with H plus, okay.

So here we can say this in the feed side copper 2 plus and oxime H plus will be there, will be converting into copper 2 plus into oxime plus H plus. In the permeate side copper 2 plus and oxime plus H plus actually will be giving oxime and H plus and releasing Cu2 plus, okay.

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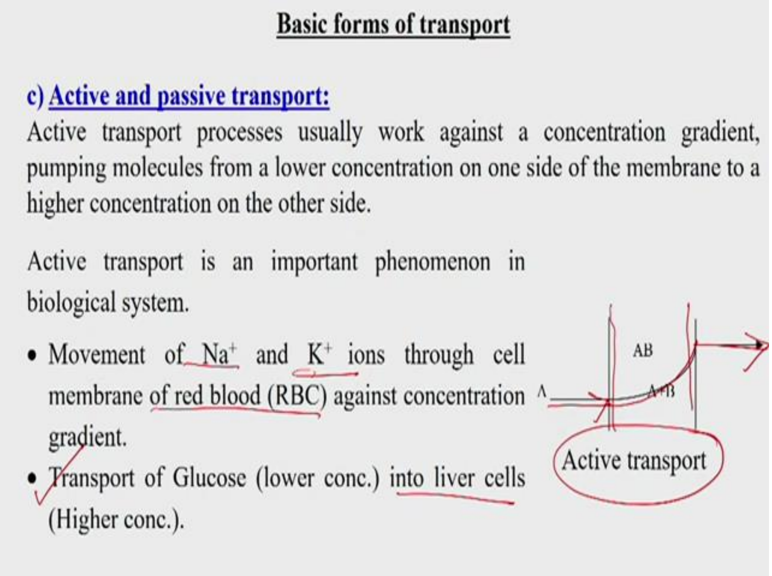

Third and last form of transport is active and passive transport. So in active transport process it generally works against a concentration gradient like pumping molecules from a lower concentration on one side of the membrane to the higher concentration at the other side. So active transport is an important phenomena in biological systems like movement of sodium plus and potassium plus ions through the cell.

Suppose this is the membrane, so through this we can say this one A is moving from low concentration to this high concentration zone. So that is actually we can say this one active transport like say sodium plus and potassium plus ions through the cell membrane of this red blood corpuscles against concentration gradient and other type of transport like this of glucose into liver cells is from the lower concentration to the higher concentration.

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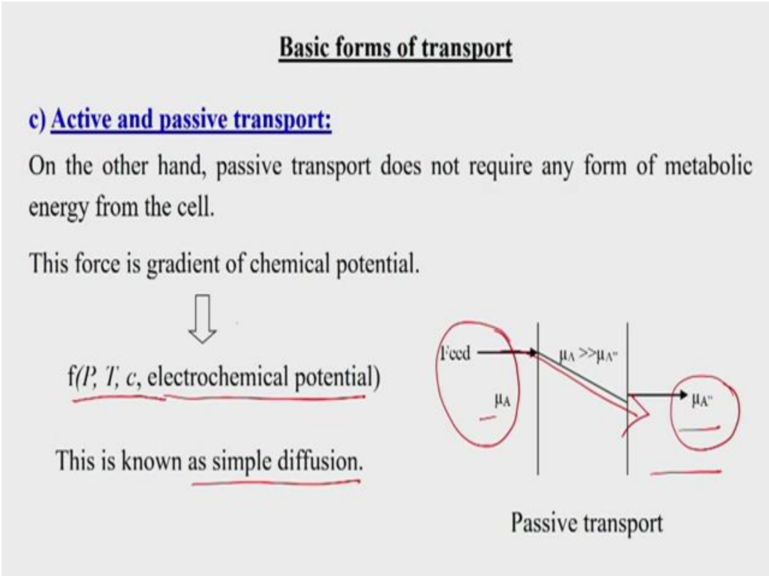

But in case of this passive transport it does not require any form of metabolic energy from the cell. It can go move from higher concentration to lower concentration due to the chemical potential gradient like this. So that will be the function of this temperature, pressure, concentration, electrochemical potential like this is actually we can say is just like simple diffusion process. So in other words we can see this is passive transport, okay.

Like say feed has this chemical potential of mu A due to this chemical potential value low in the permeate side or we can see this one in the strip side. So a particular target component A will diffuse due to this passive transport or we can say this is one test by simple molecular diffusion, okay.

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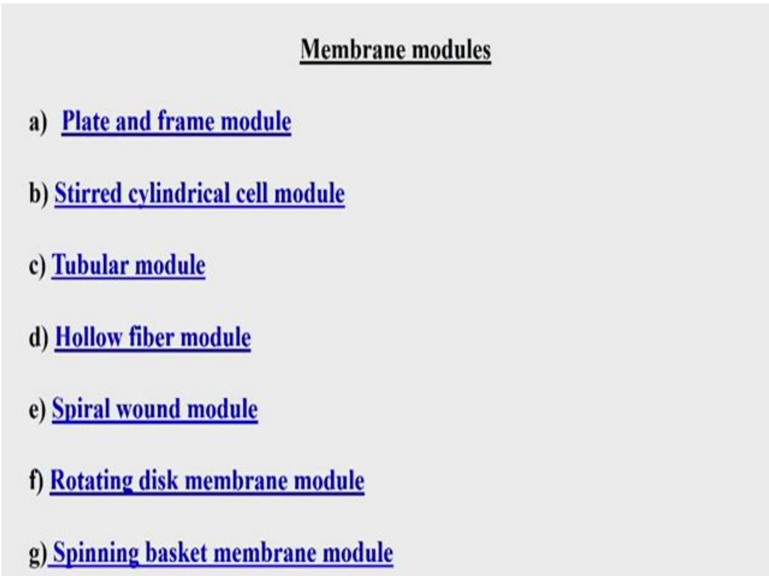

So now we will be discussing about the membrane modules. So there are so many different types of modules available for this industrial application, for the academic research also in the lab scale, in the pilot scale or in the industrial scales also. First type of simple module is plate and frame filter. That is we can say plate and frame membrane module then we have stirred cylindrical cell module then third one is tubular module and fourth one is hollow fiber membrane module.

Fifth one is spiral membrane module then sixth one is rotating disk membrane module and seventh one is spinning basket membrane module. So other membrane modules also are available which are we can say this one pilot scale as well as industrial scales also. We will be discussing briefly all these membrane modules.

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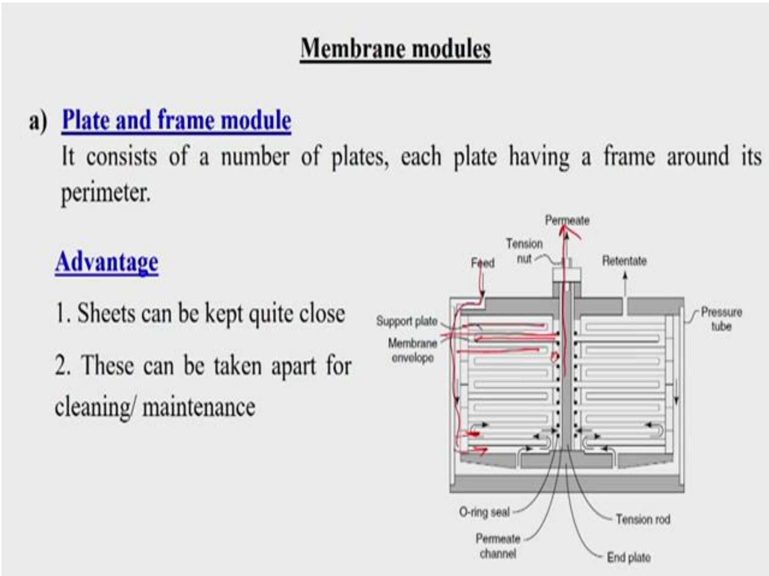

Like for Plate and frame membrane module this is very simple. We can say it consist of number plates and each plate having a frame around its perimeter and say all the plates and frames are like stacked one by one like this and in between plate and frame this membrane will be placed. Suppose membrane is placed here. In general what is happening? Over this frame the membranes are placed.

So if we place the membrane in the two sides of the plate then another frame actually will come and then we can say whenever this feed will be entering then feed will be entering actually in all the frames and through frames this feed will enter and suppose in some cases the Sunrise type groups are there. Through this group and from the corner of this plate the permeate we will be collecting and then it will be collected in common header and it will be taken out from the plate and frame membrane module. It is simply we can say plate and frame filter type.

Advantage is that these sheets can be kept quite close and these can be taken apart for cleaning and maintenance. Just if we open these plates and frames, the frames from all the plates then we can reuse these plate and frame membrane module very easily. And if it is choked also, we can clean this very easily and that is why we can say this one maintenance of plate and frame type membrane module is very easy.

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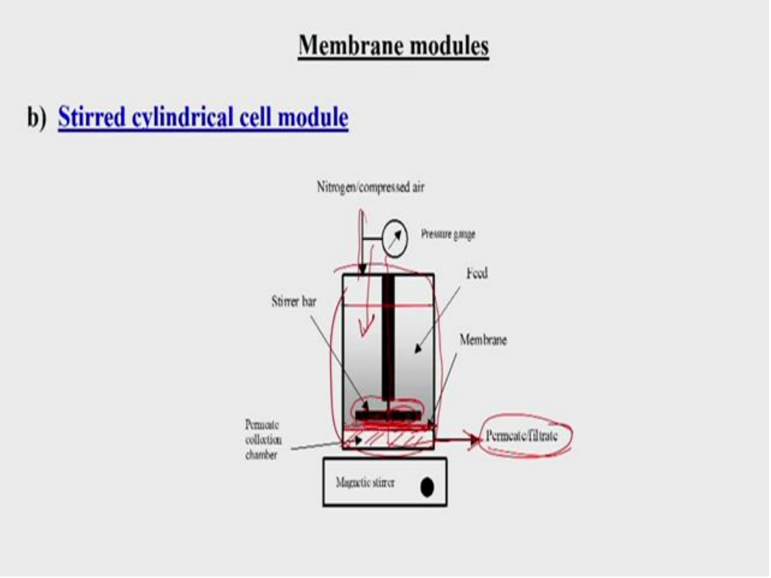

And then second type is the stirred cylindrical cell module like this is a cylindrical cell and say this is a vast cell. So in the beginning we need to feed this feed inside this membrane module up to a certain height then we need to pressurize the system as per requirement of the membrane system. If it is a micro-filtration, low-pressure is required; if it is a reverse osmosis then high pressure is required.

And then above this membrane, suppose this is the membrane material then above this membrane suppose one stirrer is there. This stirrer maybe, magnetic stirrer, it may be mechanical stirrer whatever this arrangement is there it is fine with the system. So to reduce this concentration polarization we will be discussing about this concentration polarization in detail at the end of this lecture. So something will be deposited on this one, the solute will be deposited as the solvent will be coming out from the system.

So we consider this permeate or filtrate is devoid of the solutes, so solute condensation will go on increasing on the membrane surface. To reduce this concentration polarization stirrer bar or sometimes using this mechanical stirrer that can be stirred. So the solute concentration at the membrane surface will decrease and then we can say the efficiency of the membrane filtration process will go on increasing with time, okay.

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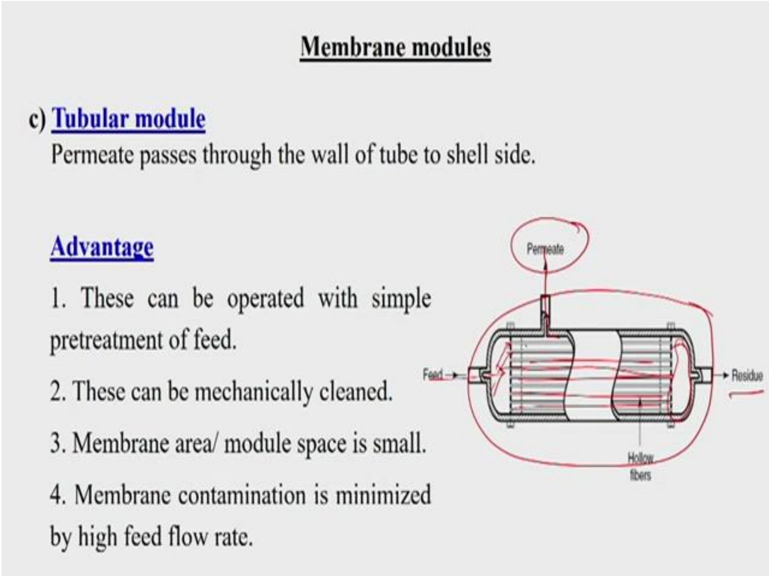

Then third type is tubular module, so it is simply we can say this one like cell and tube heat exchanger. So all these we can say tubes are placed inside one chamber like this and then feed is entering from one side of this tubular system and the feed will be now distributed among all the tubes. And from the tube side the permeate will be collected and then that will be taken out from the system.

But the concentrated residue or we can say this one retentate will move through these pipes or we can say tubes and will be collected from the opposite side of this we can say this bundle and then it will be taken as the concentrate or retentate or rejecter. So there are so many advantages of these tubular modules like this can be operated with simple pre-treatment of feed and this can be mechanically cleaned just by we can say this one opening the tubes from the tube sheets and we can clean this one using this brass or like this and then again we can place this one inside the cell.

And membrane area or module space is small and membrane contamination is minimized by high feed flow rate because that time the solute deposition may be minimized inside these tubes in the tubular membranes module.

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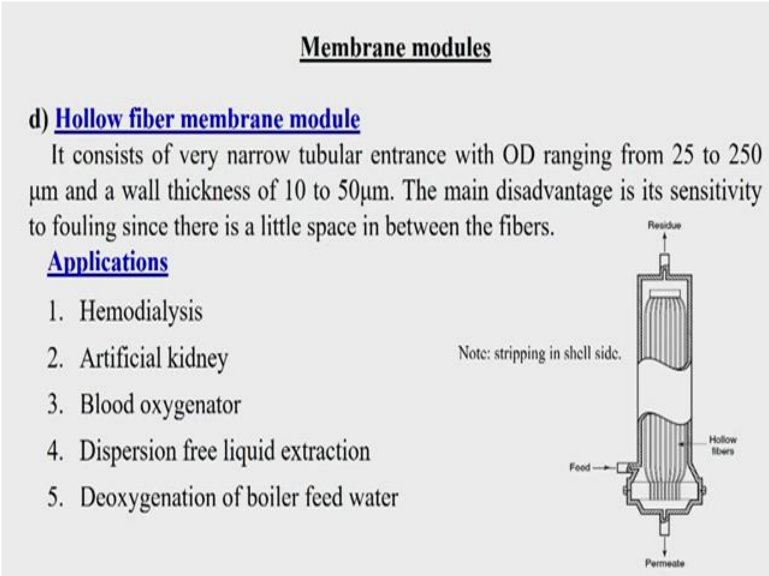

Then fourth type is hollow fiber membrane module, this is the another form of the tubular membranes but it consist of very narrow tubular entrance with outer diameter ranging from 25 to 250 micron and a wall thickness of 10 to 50 micron of these narrow fibers. The main disadvantage is its sensitivity for fouling since there is a little space in between the fibers. So we can see this one the tubular module and hollow fiber modules both are almost same and operation wise we can say this one also same.

Only the difference is that in case of tubular modules we have these big tubes but in case of these hollow fiber modules, all the fibers are with very low inner diameter as well as this outer diameter. And there are so many applications mostly the hollow fiber membrane modules or cartridges are used in hemodialysis and then artificial kidney, then blood oxygenerator then we can say this one dispersion free liquid extraction then we can say this one deoxygenation of the boiler feed water and so many other applications.

But main disadvantage of this cell is that these fibers are contaminated very easily because the clearance between these 2 fibers are very less and once this small particle is also stick inside this one, it is very impossible to clean this as the inner diameter of the fiber is very less. That is why these are prone to choking and then efficiency of the membrane, cartridge will decrease very drastically.

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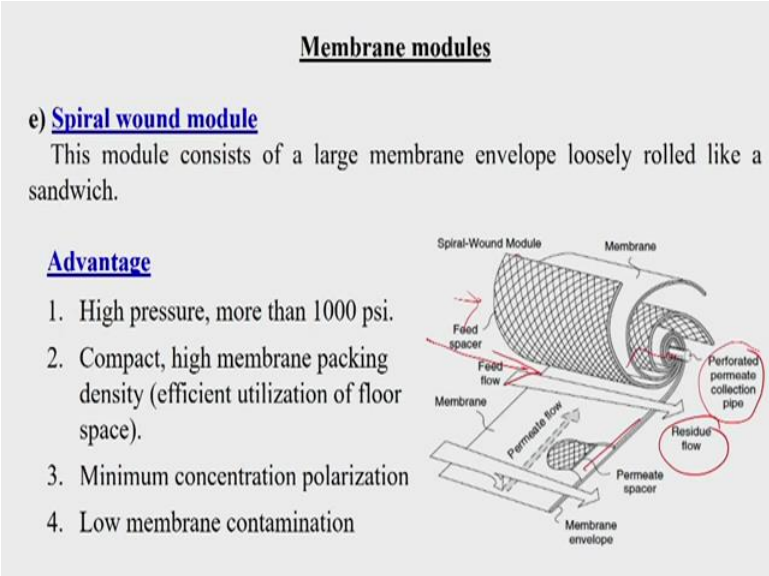

Then fifth type of this module is the spiral membrane module. This is widely used in so many industrial applications, so this module consists of large membrane envelope loosely rolled like a sandwich. So in between say two membranes suppose one spacer actually is used. Spacer is nothing but a great type of material made of these metals and these great or we can see this one spacer gives the entry point to the feed.

So suppose if we have two meals like 2 sheets are available then in between 2 membranes sheets one spacer is placed and then it is rolled and it is kept inside one cartridge and feed is entering. So we can say this one from one side of this system and then feed will be distributed among all the…suppose feed is entering from any side and then see whenever feed flow is in this direction and in all the open channels feed will be distributed and permeate will be collecting through the spacer in a common header and that will be collected in the perforated permeate collection pipe where we can say these membranes are housed, okay.

And residue will be collected from the other side of this wound and there from the common header the residue or we can say retentate or reject will be collected. The main beauty of this spiral membrane module is that in a small space we are able to provide huge surface area. For 1 meter square membrane surface area we need only a small 1.5 feet long tube with only 3 to 4 inch diameter and this tube sheet is sufficient to keep 1 meter square area.

And it can withstand up to high pressure like more than 1000 psi pressure also. This is compact and high membrane packing density. So we can see the efficient utilization of floor space. And minimum concentration polarization and low membrane contamination. This is very easily cleaned, this spiral wound membrane module.

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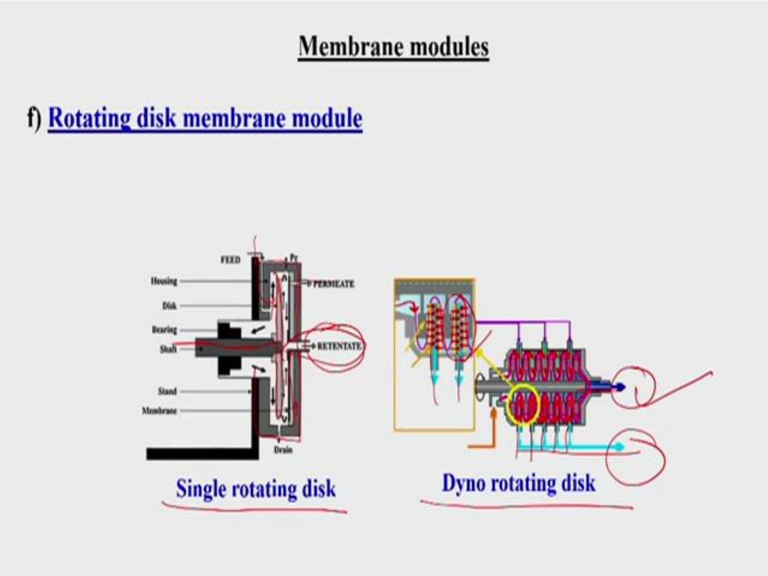

Another one is this rotating disk membrane module, so once disk actually is placed with the shaft of this one driving motor and then suppose this feed is entering from one side of this chamber. Like you see the chamber and then in case of this highly concentrated feed, we can use this rotating disk and then membrane is placed here and through this membrane say permeate we will be collecting and then it will be collected from one particular point and retentate will be collected from one common header type thing.

And whenever the solute will be deposited on the membrane surface due to this rotation of the we can say disk, the concentration polarization or deposition of the solute will decrease. I told that this is mostly efficiently used for this highly concentrated feed or we can say this highly viscous feed, okay. And so this is we can say the single rotating disk. We have this multiple rotating disk that is called dyno rotating disk.

Suppose the retentate is coming from one rotating disk membrane module. If it is fed in the next one like this, if it is fed in this like the next one, so then here also again we will be getting retentate and permeate also. So whatever permeate actually we will be collecting every permeate we will be collecting power so many rotating disk systems and then one through common header we will be collecting the permeate and whatever the retentate we will be getting from the we can say conjugative steps or we can say these systems these will be collected in a common header, then retentate will be collected from one common outlet, okay.

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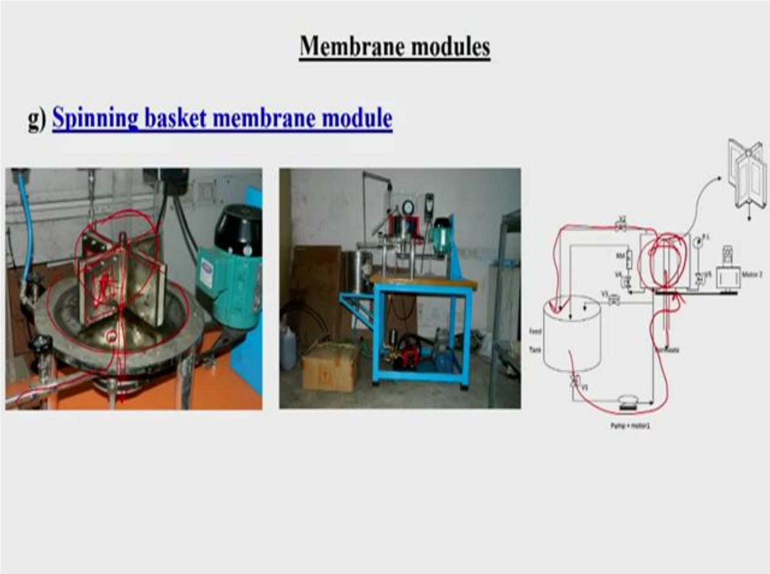

And the last one we can say the spinning basket membrane module. We can say this membrane module is the recent development of the membrane modules. So here the disk itself is rotating and suppose we can say this agitator contains the membranes. Suppose this agitator has 4 plates, so in 4 plates these are hollow agitators and all these are connected with this one common header, we can say this one permeate collection line and all the agitator blades in one place the membrane is placed.

Suppose the opposite side of this plate, the membrane is placed like that in this side, so in one side of the agitator blade membrane is placed. So we have 4 membranes in 4 different blades in the same orientation and the common header is like this, this is the rotor of the agitator. And say whenever we will be placing this one tank like thing over this membrane module then through there actually we will be putting the retentate line.

So feed actually is entering from the bottom of the system. Like you see the feed line, so feed is coming and then it is entering through this hole and initially it will fill. In case of the slurry materials it is observed that after sometimes the slurry will become very concentrated and it will try to be re-deposited over this we can say this tank. But in this case the membrane is not placed at the bottom.

So this membrane will not be choked but membranes are all placed vertically on the agitator blade. So whenever it will be rotating then due to the centrifugal force the solvent will be entering through this membrane and it will be collected in a common header and then we will be getting the permeate. So whenever we will be working with slurry type material with high concentration the spinning basket membrane module actually is very much effective.

Like this, this is the spinning basket membrane module, from the feed tank it is entering from the bottom and permeate collecting from the common header and retentate will be again recycled back to this feed or whenever we require this we can take out retentate from the outlet of this tank, like this. So that is why from this basket from the top of this basket we will be able to collect the retentate or highly concentrated slurry and from the bottom we will be able to collect this pure permeate or we can say permeate without the slurry materials.

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Thank you.

So in the next class we will be discussing about this manufacturing of the membranes then advantages of the membrane separation processes and limitations and approaches to improve.