Downstream Processing
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Lecture - 21
Membranes

We will continue with the topic of a Membranes, membranes are very, very important in removing solids for purification on separating out proteins based on their molecular weight. And because, they are operated at home temperature, it can be used for biomolecules and we can be very sure that they will not lose their activity.

In the previous class, I introduce the concept of membranes, so we shall continue with the same topic. So, membranes are about a 150 micron thick and you also have thin membranes, which are 1 micron thick that means, you can have really very thin polymeric material, which can act as a barrier.

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So, look at the total world wide consumption of membrane this is a 2001 data based on the surface area 85 percent is RO membranes. That means, reverse of osmosis composite membranes and then you have the nano filtration membranes coming in, an you have a again nanofiltration of made up of composite material, you have polysulfone membranes and then microfiltration membranes.

So, a large number of membranes are use for reverse osmosis as I had mentioned in the previous class, reverse osmosis is used for desalination of water, I am removing all the dissolved salts present in water and the N product is something that is drinkable or potable.

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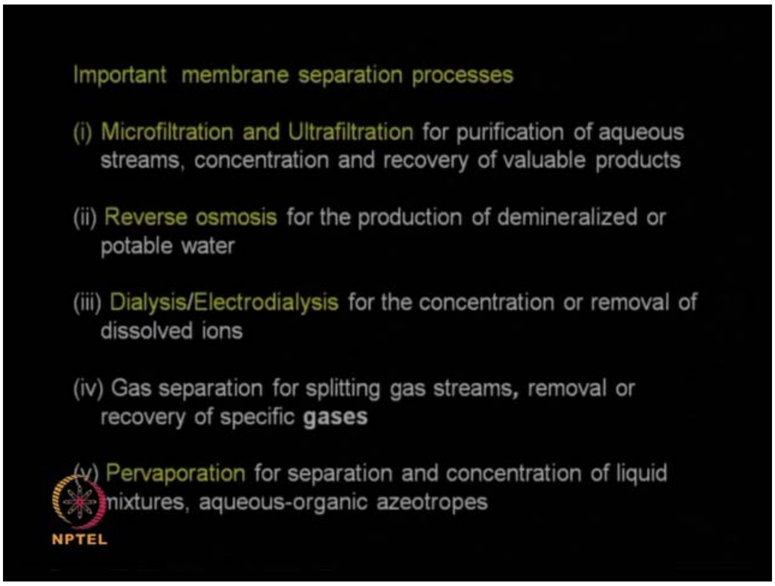

So, different types of membranes again, I am this slide you might have seen in the previous class, you have the microfiltration, ultra filtration, nanofiltration and so on. So, it is good for a concentration, it is good for recovery of the desired product and it is good for removing lot of salts or solids present in aqueous streams, then we have the reverse osmosis and it is used for desalination of water. So, we can be use for demineralization and preparing potable water.

Then we have the dialysis and electro dialysis, dialysis is used in a hospitals where patients have problems in their kidney, where they are not able to separate out urea, then we have the electro dialysis, which works on the principle of using in electric fields for separating cations and anions. Then we have the gas separation membranes for separating gas streams based on the diffusion coefficient of the gas streams.

Then we have the pervaporation membranes, where you are having a certain solute, which will sort of evaporate and then it will permeate, through the membrane material. So, pervaporation membrane does not have any porous like a filtration, but here there is a diffusion of the solute take place. So, that is what called a pervaporation membrane.

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Characteristcs of membrane separation processes

Process	Driving force	Characteristic features membrane pore size	Separation mechanism
MF	Pressure 0.1-1 bar	0.02-10 μm	Sieving
UF	2-10 bar	0.001 – 0.02 μm	Sieving
RO	10 – 100 bar	Non- porous	Solution diffusion
Dialysis	Concn differences	1-3 nm	Sieving and diffusion
Electrodialysis	Electrical potential	Mol.wt < 200	ion migration

Now, there are certain broad categories under, which each membrane could be grouped into and that is what the this slide and next slide is going to tell you, we look at microfiltration. The generally the pressure is reasonably good that means, it separating at either vacuum or at near atmospheric pressure.

So, it can remove large particles 10 micron particles. So, the principle is based on sieving that means, it is got lot of porous and depending upon the porous size, the particles are the larger than the porous size, the get captured and smaller particles and salts travel through, that is what a microfiltration does.

If you look, if you go to ultrafiltration and here the pours sizes are much smaller and that is why you are able to capture much smaller particles. Hence the pressure drop is also very high. So, the driving force is almost 10 bar here, you can see this 10 bar, again the principle is the same you have a sieving action that means, rough force.

Now, when you come to reverse osmosis r o membrane the pressures are extremely large, we can even have 100 bar pressure here. And there are no force we have because, there is a osmotic pressure and then, you are applying pressure against the osmotic pressure. So, there is a diffusion type of phenomena taking place that is how reverse osmosis works are shown here.

Now, any come to dialysis based on concentration like I said dialysis is used for patients, who have problem with the kidney. So, the salts urea percent in the blood will travel through the dialysis membrane and come to the other side, there by the blood gets the purified from salts, again the principle here is diffusion sieving electro dialysis you are applying a large electric field. So, the cations and anions get separator based on the direction in which you are applying the electric field. So, we can separate out material or compound’s molecular weight less than 200.

So, there is an ion migration taking place in a electro dialysis. So, in electro dialysis we can have a cation selective membranes, anion selective membranes and so on actually. That means, the cation membranes will allow only, cation pass through it will not allow any anions and anions selective membranes will just pass, anions it will not allow any cations.

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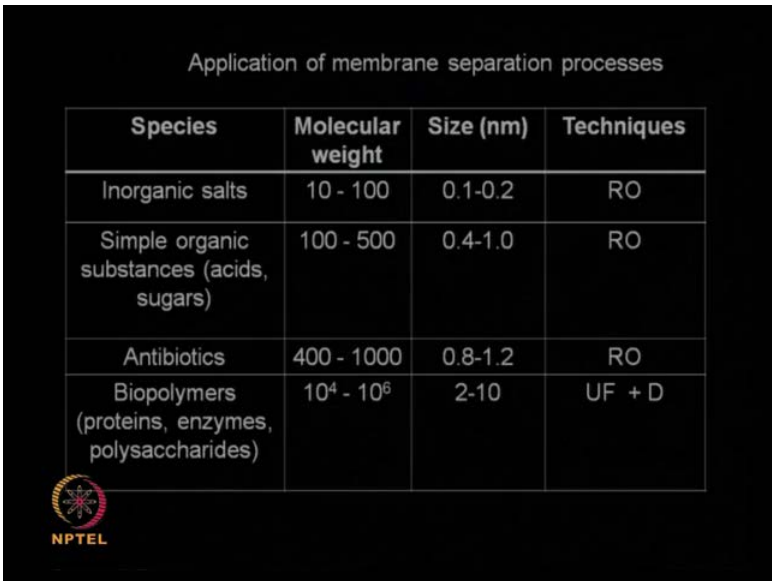
Application of membrane separation processes

Species	Molecular weight	Size (nm)	Techniques
Inorganic salts	10 - 100	0.1-0.2	RO
Simple organic substances (acids, sugars)	100 - 500	0.4-1.0	RO
Antibiotics	400 - 1000	0.8-1.2	RO
Biopolymers (proteins, enzymes, polysaccharides)	10^4 - 10^6	2-10	UF + D

So, where do you used membranes, we can use it for separating out suspended solid a generally for a suspended large solid, we use say normal filtration. We can use it for divalent or multivalent salts, we can use it for monovalent salts, we can use it for bacteria, enzyme, other proteins, bio polymers and so on. So, we can use this separations, so if, we have an organic salts, molecular weight 10 to 100 and size 0.1 to 0.2 nanometer R O membranes is good. The simple organic substance again acid sugar molecular weight 100 to 500 size about 0.4 to 1 nanometer that means, slightly big again R O is big good.

The antibiotics and them I want to separate out antibiotics in a molecular weight range 400 to 1000 a sized is also pretty large 0.8 nanometers to 1.2 nanometers. And again, we can use a R O type of membrane and it is really good, then if you have biopolymers, what is the biopolymers.

Biopolymers could be proteins, it could be enzymes, it could be polysaccharides earn very large molecular weight biopolymers, we are talking in terms of a 10 power 4 to 10 power 6 dalton. So, big size 2 to 10 nanometers. So, here we can use ultra filtration and type of system, because the sizes are much much larger here and like the other cases.

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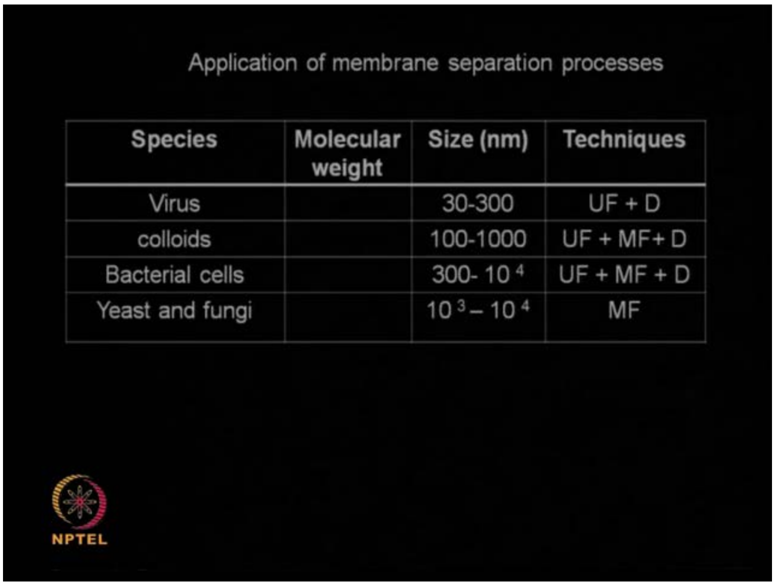

Application of membrane separation processes

Species	Molecular weight	Size (nm)	Techniques
Virus		30-300	UF + D
colloids		100-1000	UF + MF+ D
Bacterial cells		300- 10^4	UF + MF + D
Yeast and fungi		$10^3 – 10^4$	MF

We want to separate virus, colloids, bacterial cells, yeast, fungi and the sizes are much larger. So, we can use ultrafiltration microfiltration dialysis. So, many different types of technique of possible depending upon the nature of product and what is present in addition to the material, you want to filter out.

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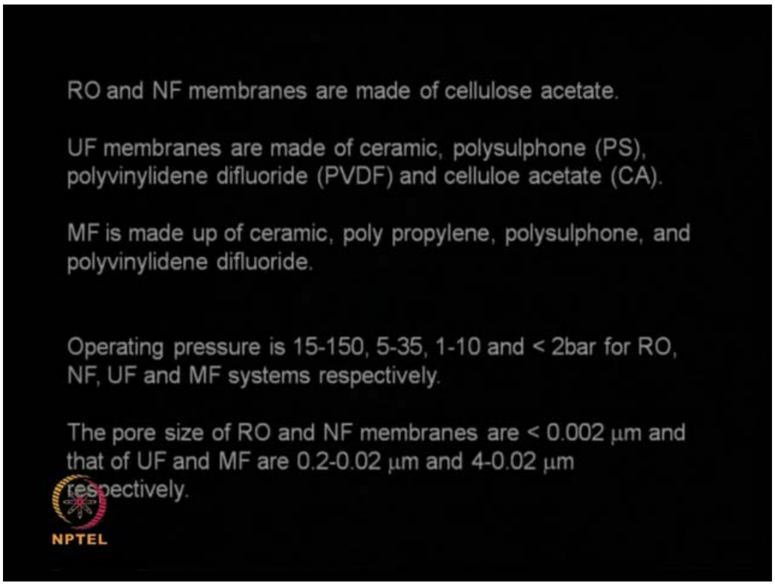

Now, let us look at the material of construction of these membranes look at R O and nanofiltration membranes, they are made up of cellulose acetate, cellulose a being a hydrophilic and it will favor hydrophilic compounds. If you look at ultrafiltration membranes, they are made up of ceramic, polysulphone, polyvinylidene, difluoride that is P V D F polyvinylidene difluoride and cellulose acetate, that is C A. Look at micro filtration, it is made up of ceramic, poly propylene that means, we can go to highly hydrophobic polysulphone again pollyvinylidene, difluoride. So, different types of material.

Operating pressures varies quite large depending upon the type of a process, which we are under taking. Reverse osmosis as I said very pressure, if you go to nanofiltration, it may be 5 to 35 bar that is takes place. They go to ultrafiltration, we are talking about 1 to 10 bar that take talking about microfiltration, which almost atmosphere repression system. So, sometimes if you want to do a R O type of job, you may have via in ultrafiltration before to capture as much as dissolved solids and suspended solids, then you may go to via r o type membrane.

Look at the pore size of a R O is very very small and practically no pore size at all. And if you look at ultrafiltration pore size is much larger, micropiltration is much much larger pore sizes.

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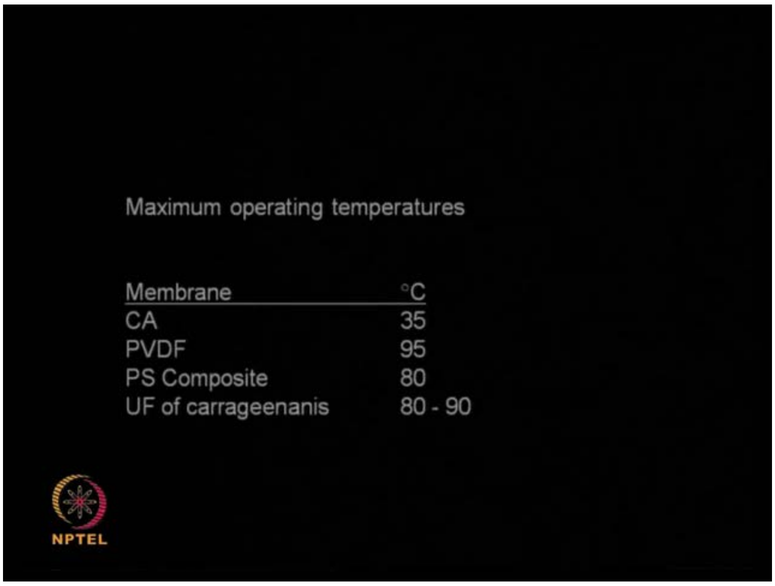

Now, you have to keep this in mind that you canoid have very high temperature of operation, if you are using membrane. So, cellulose acetate, we can go only up to 35 degree. So, if we solution is very hot, if you need to cool it down. Look at P V D F, we can go quite high almost 95 degrees and polysulfone composites about 80 degrees and carrageenanis about 80 to 90 degrees.

So, but the polymer type of material hydrophilic material temperatures our always have to be very very less. Hydrophobic synthetic polymer, if you are using even poly carbonic or polyethylene, we can go up in temperature of operation.

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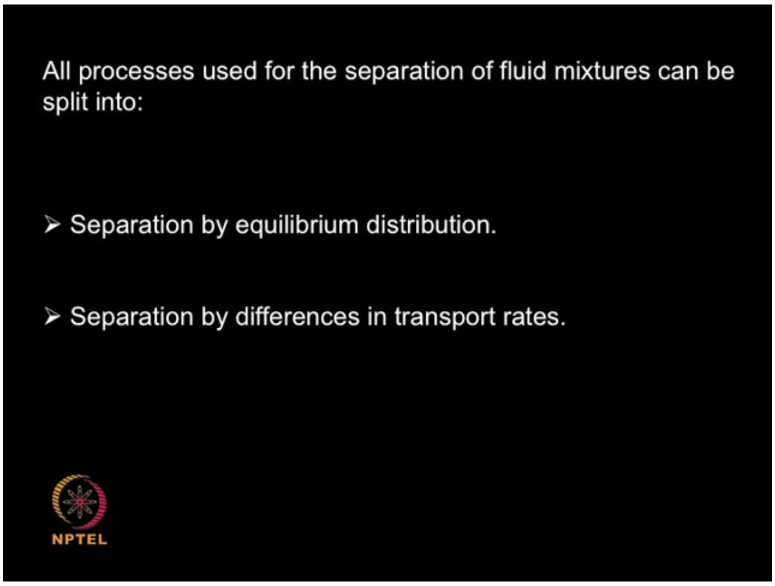

Now, the separation takes place because, of equilibrium distribution or partition coefficient and so on or it takes place because, of the transport rates some material travel faster some materials travel slower. So, the materials travel faster move from one side of the chamber to the other side, materials travelling slower will be left behind. So, it is based on either equilibrium, it is based on differences in transport. These are the principle by which it works.

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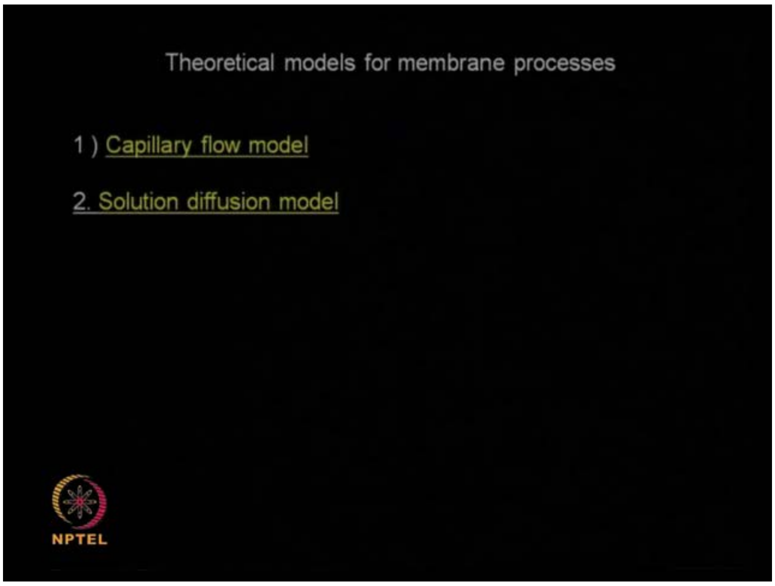

Now, last class I introduced that there are 2 models, I am using which, we can try to approximately model in membrane processes say, which either are capillary flow model or it is a solution diffusion model. So, in a capillary model what happens, you have a like particles, you have interstices and capillary like. So, the liquid flows particle, which are very small particle, which are smaller than those holds will travel with the solution or solvent larger particles will get a entrapped. So, that is the capillary flow model.

In the solution diffusion model there is just a diffusion taking place fix law of diffusion like. So, it is based on the concentration gradient. So, many systems may have combination of both, if you take a there are some systems will just depend upon only one type of model. For example, if you are talking about sieving, then it will be a capillary flow model, if you are talking about I think like pervaporation, it could be a diffusion model.

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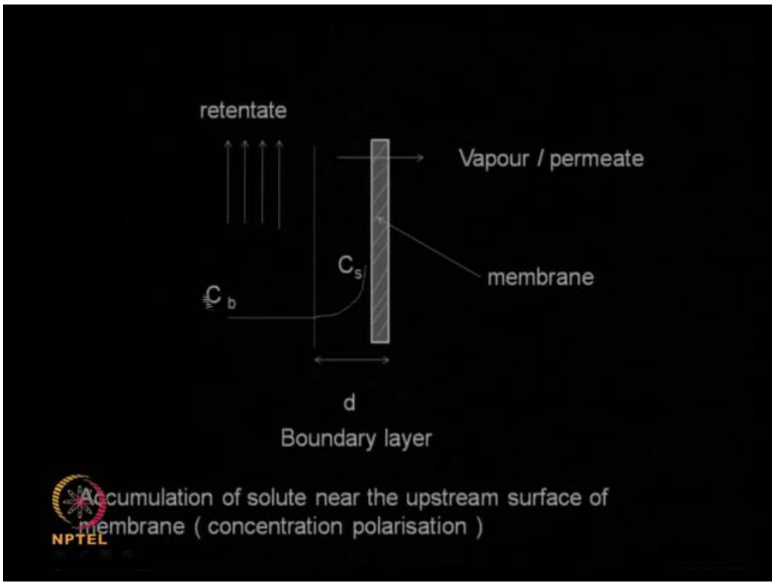

Now as the membrane process takes place and if the vapor or liquid flows perpendicular to the membrane surface, what happens this is a membrane surface. I said there is going to be an accumulation of solute nearly upstream surface of the membrane, this is the called the concentration polarization. so the normally, the concentration near the upstream will be much larger than the bulk concentration, it C ds or bulk concentration and C s is the concentration near the surface, C s will be much larger than C d.

This is called concentration polarization, it is lot really good, because as time flows, because C s is larger than C d. The diffusion of the solute from the bulk coming down to the surface on the upstream of the membrane is going to get slow down, because of the concentration polarization. And assume this is as your boundary layer, this is always going to be a must and should boundary layer.

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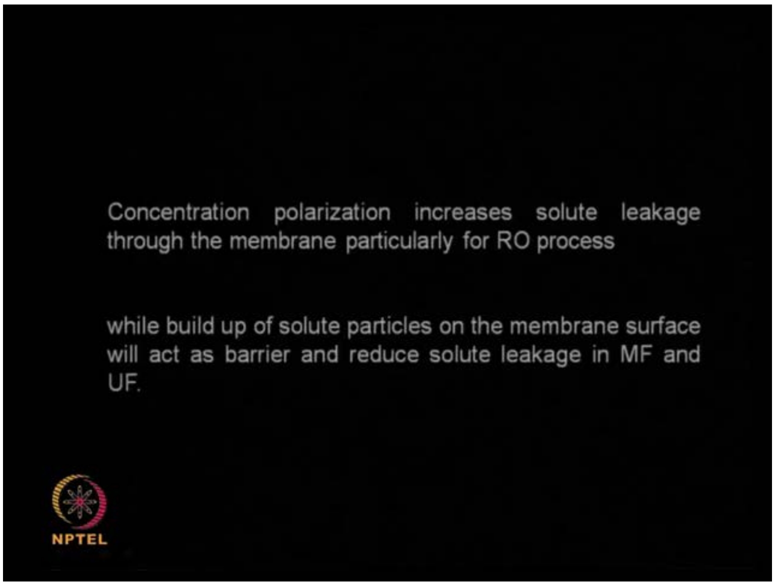

This is a concentration polarization increase a solute leakage through the membrane particularly in R O, because the concentration on the upstream very near the surface of the membrane is large. So, this going to be a solution leakage, where as a buildup of solute particles on the membrane surface will act as a barrier for micro filtration ultrafiltration.

Because, the diffusion of the solute from the bulk coming near the upstream of the surface of the membrane is going to get slow down, because the C s that is the concentration near the surface is much larger than C b, which the concentration near the bulk.

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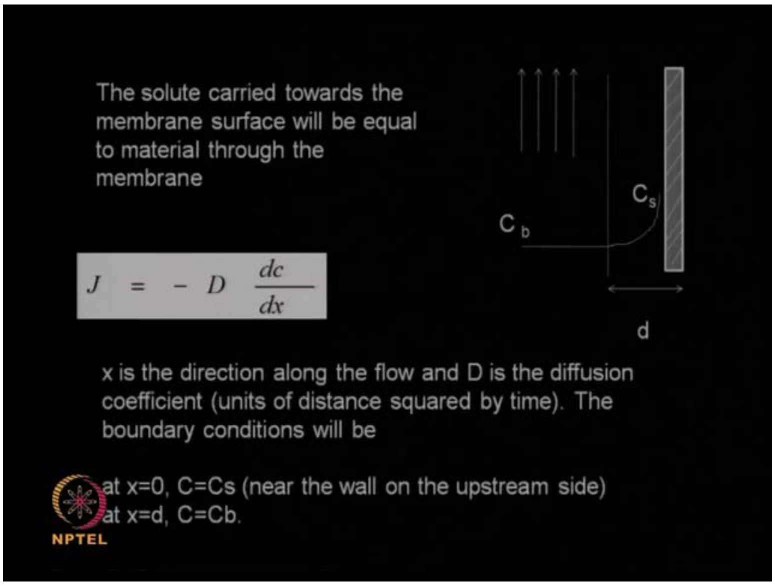

Now, let us look at some mathematical jugglery and calculate, what will be the concentration polarization as we move from the bulk of the liquid right to the surface of the upstream of your membrane. Now we use a fix law of diffusion for doing this, because whatever solute that is getting carried towards membrane surface will be equal to the material that is passing through the membrane. So, the flux J is equal to minus D that is diffusion coefficient d c by d x. C we can call it concentration x is here, the distance that is the boundary layer distance along the direction of the flow.

So, what will be the unit of diffusion coefficient, it will be distance squared by time. Now the boundary conditions, what are the boundary conditions that means, add the wall on the upstream side, you are going to have C is equal to C s and at x equal to D, that is the boundary layer C is going to be C b. So, we can just solve this differential equation.

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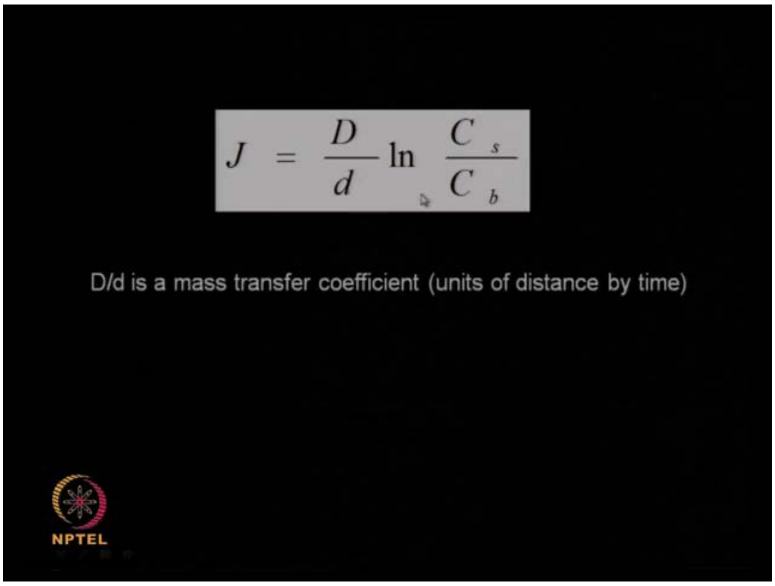

And we can apply the boundary conditions, do that what will happen, we get a nice equation, this is a first order differential equation. So, it is very simple to solve. So, we will get J equal to D divided by D logarithm of C s by C b, C s is the concentration of the solute on the upstream. Because, of the concentration polarization near the surface of the membrane upstream and C b is the concentration in the bulk.

C s will be larger than C b, now D by D that is D is the diffusion coefficient and this D is D thickness of a your boundary layer. Now this is call the mass transfer coefficient D by D and it will have units of distance by time units of distance by time. So, we have a equation, which tells you the flux of the solute will be a function of a mass transfer coefficient and the logarithm of the concentration and upstream near the surface of the membrane divided by the concentration of the solute in the bulk region.

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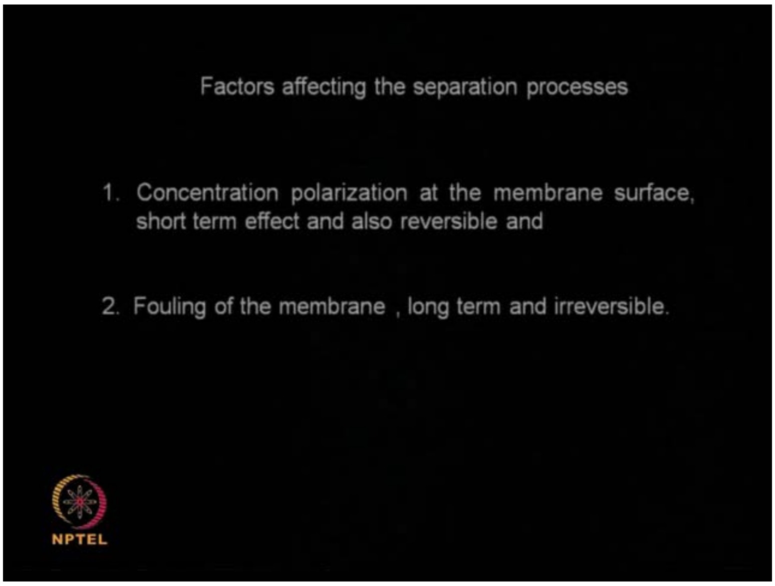

Now, what are the factors that affect your separation processes in membrane, 2 factors you need to keep in mind, 1 is the concentration polarization like, we talked about in ultrafiltration. It will slow down the process in R O, it will have there will be a leakage of the solute on the other side, because C s is very very large.

So, 1 factor, which affects is the concentration polarization, the other factor will be fouling of the membrane. Now this is a long term process, this is an irreversible concentration polarization I see at least reversible, I can stop the process and I can do some cleaning I am and or a then again start my membrane process C s will be equal to C b. So, it is a reversible process very short term effect, where as the fouling is the long term effect and it is irreversible.

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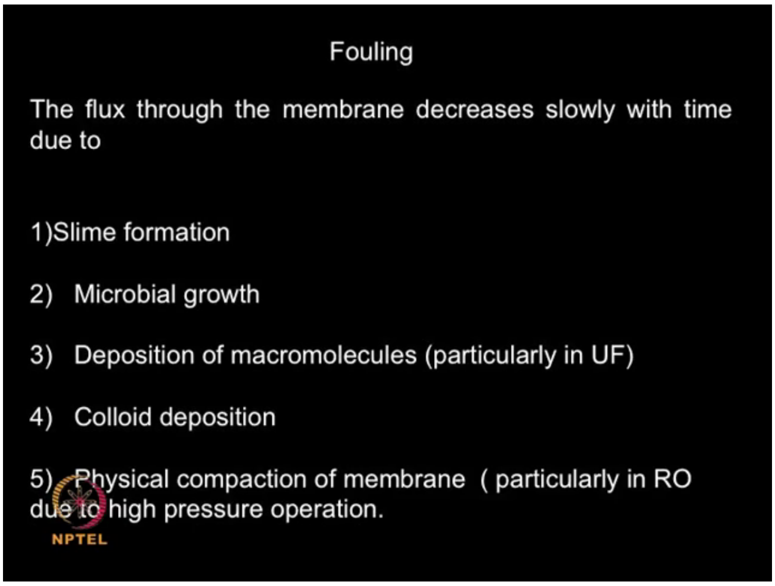

Fouling happens because of so many factors, fouling happens because of bacterial material present, fouling happens because of a these dissolved salts that are present, fouling happens because changes in P H, which will allow your salt precipitate out and fouling happens because of colloidal suspension, which gets agglomerated and so on. So, all these factors lie to fouling and there is going to be deposit of material on the upstream and surface of your membrane. So, the entire membrane filtration gets slow down as time goes on

So, the flux get affected over a period of time, because of slime formation, because of microbial growth that means, you can have bacteria, algae, fungi all those things deposition of macromolecules. Especially, in ultrafiltration membranes, because ultra filtration may be having lot of proteins and other material, colloidal deposition lot of colloids salts, physical compaction of membrane. Because, you are applying such high pressure especially in r o, that the whole membranes gets collapsed and get compressed, that is called the physical compaction.

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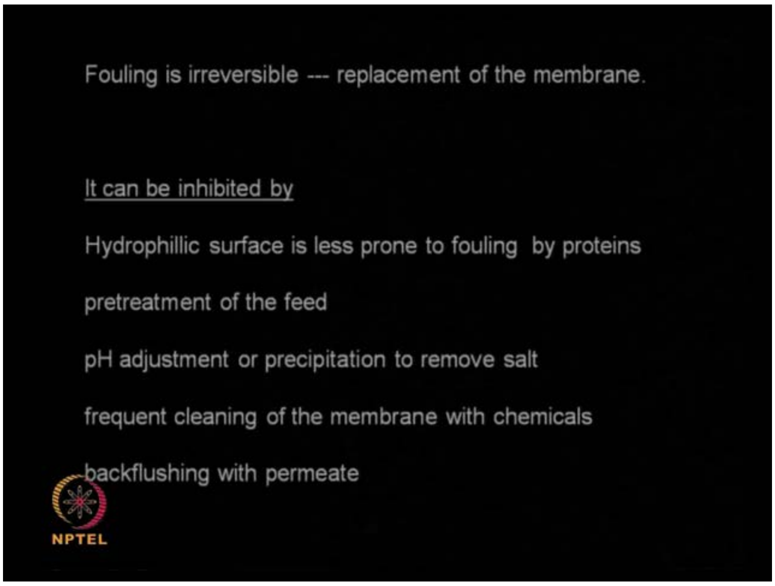

So, all these factors affect your filtration process, it gets low down and slow down and after sometime it is not very efficient to run your membrane. So, you need to stop and we need to remove all the fouling or if it is irreversible, we need to completely change your membrane. So, that becomes very expensive changing membrane is very expensive because, most of the cost is the cost of the membrane

So, you can inhibit fouling, you can slow down fouling by doing many things, you can make the surface very hydrophilic. So, bacterial proteins and other things do not deposit, we can do some pretreatment of the feed, the feed can be pretreated, so that there are no salt precipitating order. We can do p H adjustment or we can even precipitate all the salts before they come to the membrane.

So, you can have a precipitation chamber and then, you can move it to the membrane chamber then you can do lot of frequent cleaning of the membrane with chemicals. That also possible, so we can clean the membrane surface from time to time then we can do via black flushing that means, we can send a feed from opposite direction. So, that whatever fouling that is taken place, we will get dislarge and removed from the surface of the membrane.

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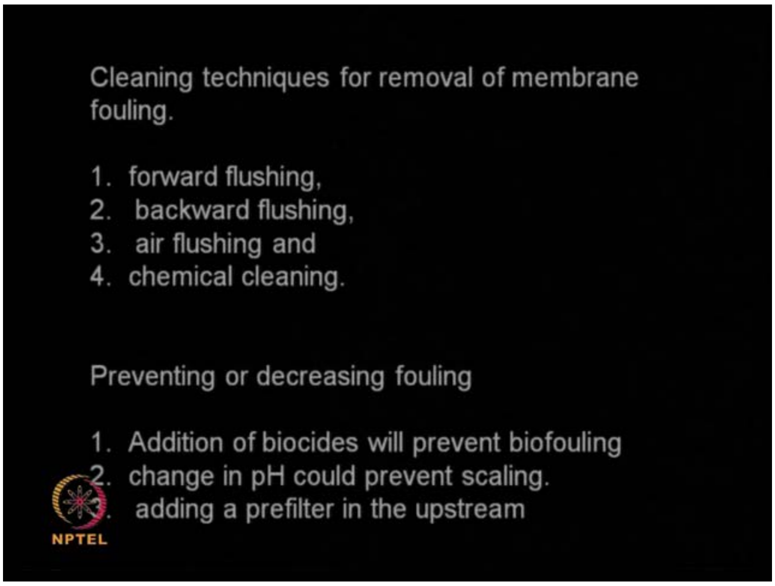

So, there are many ways by which, we can do a flushing, we can do a forward flushing, we can do a backward flushing, we can do a air flushing that means, we can just pass air. So, that the foulance that has been settle get say discharge, we can use a chemical cleaning. So, all these can be done.

How do your prevent or decrease fouling, you cannot completely prevent fouling, you can decrease it or you can slow it down. So, we can add biocides, so there is not bio fouling, we can add insecticides another chemical, which will prevent the attachment of micro organism on the surface, when micro organism settle down the form exopolysaccharide the form dead biocells, live cells, proteins, carbohydrates. So, the form something called a biofilm on top of the membrane and that completely blocks the flow of your solution.

Changes in p H, we can change the p H, so the salts do not precipitate out. So, the salts precipitating out, you are going to have lot of fouling. Another approach, we can add a pre filter that means, we can have another filtration setup, which can remove most of the dissolved solids or there are suspended solids, we can have a simple sieving filter, which will remove all the suspended solids. So, we can remove most of this type of solids by incorporating a pre filter in the process.

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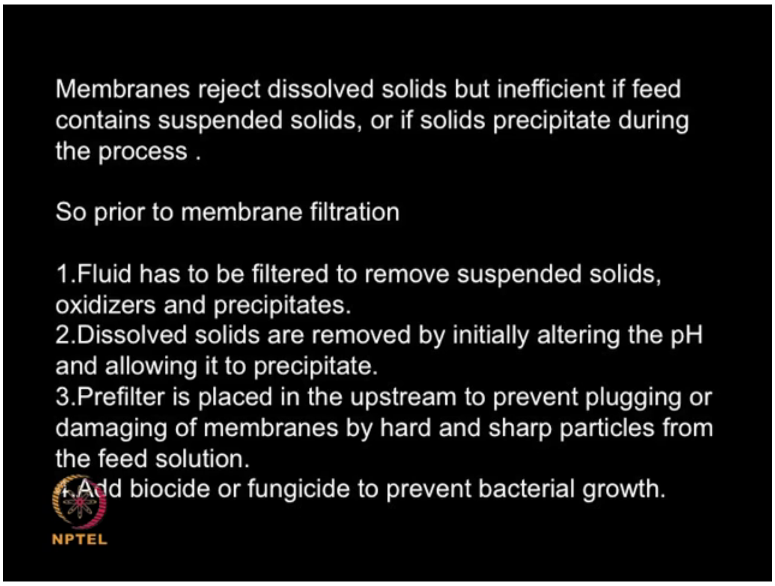

So, membranes reject dissolved solids, but then they are very inefficient feed content suspended solids. So, it is not very good to have suspended solids, if you want to sort a membrane or is the solid start precipitating out during the membrane process, when does solids precipitate out, it can precipitate out, if there is going to be change in p H or if there is going to be a colloid in agglomeration formation. So, prior to the membrane filtration, we need to have lot of preprocessing.

So, we need to remove all the suspended solids, we need to remove oxidizers, because some oxidation material may spoil the membranes surface. And if there are anything that is going to precipitate out, we need to precipitate out, then if there are any dissolved solids, we can alter the p H. So, the dissolved solids precipitated out, we can also have a pre filter.

So, that if there are any hard sharp particles, it may come and hit the membrane surface and break it, mechanically physically break it. So, we can have pre filter, then we can add biocide or a fungicide, so that you prevent bacterial growth. So, all these various operations you can perform. before you take your solution for membrane operation. So, you see that doing a membrane operation is not straight forward you may resort to quite lot of preprocessing.

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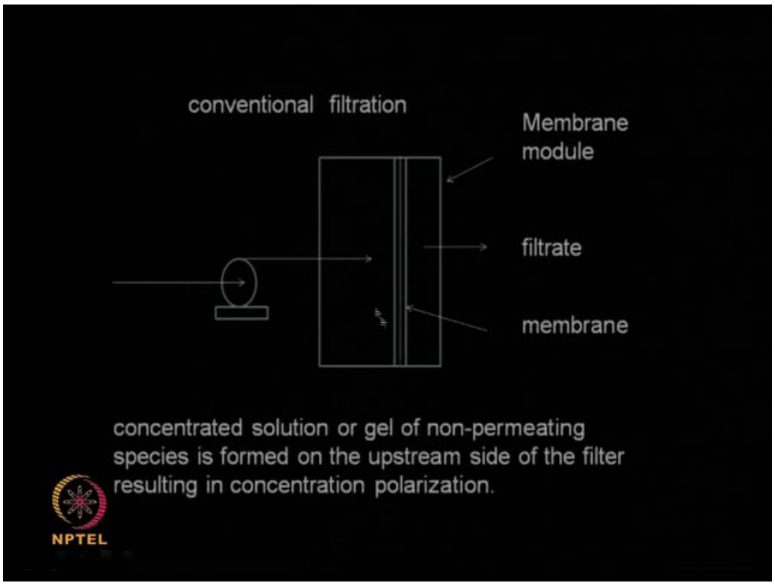

Conventional membrane filtration, you may have chamber, you have the membrane. So, this is an upstream and downstream. So, the liquid is pumpkin, the pressure defense upon the type of membrane process, you are resorting it to. So, the concentrated solution is on the upstream side of it and this is going to forming concentration polarization and here the filtrate moves on the right hand side.

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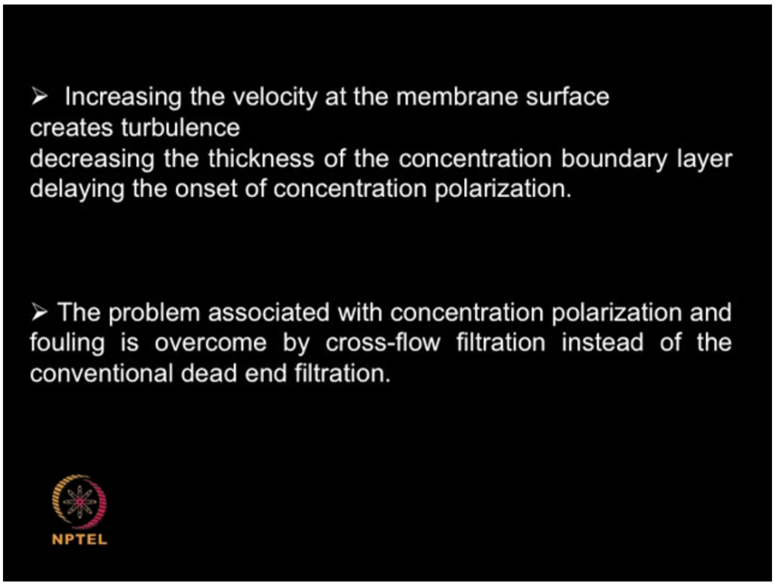

So, if you increase the velocity of the liquid flow, then it makes turbulence. So, it may decrease the boundary layer. So, when you decrease the boundary layer obviously, mass transfer coefficient will be better, because mass transfer coefficient is given by diffusion coefficient divided by the boundary layer. So, if I make the denominator smaller, you are going to have higher mass transfer.

Another way by which, you can reduce the concentration polarization is using a cross flow filtration. So, for what, we saw is a perpendicular flow that means, the flow is perpendicular to the membrane surface or the membrane surface is perpendicular to the flow direction or that it is also called dead end in filtration. So, normal filtration is also called dead end or perpendicular filtration.

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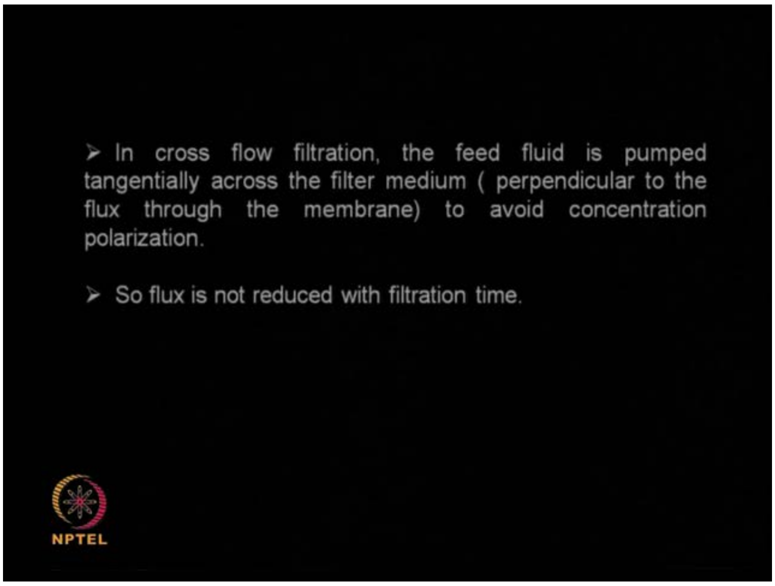

In a cross flow filtration the feed is also pumped tangentially across the membrane surface that means, instead of perpendicular it is almost flowing parallel, that way you are preventing the formation of boundary layer, you are also preventing the formation of the concentration polarization. So, the advantage will be flux will not reduce with filtration. So, that is the main advantage, when you do a cross flow filtration.

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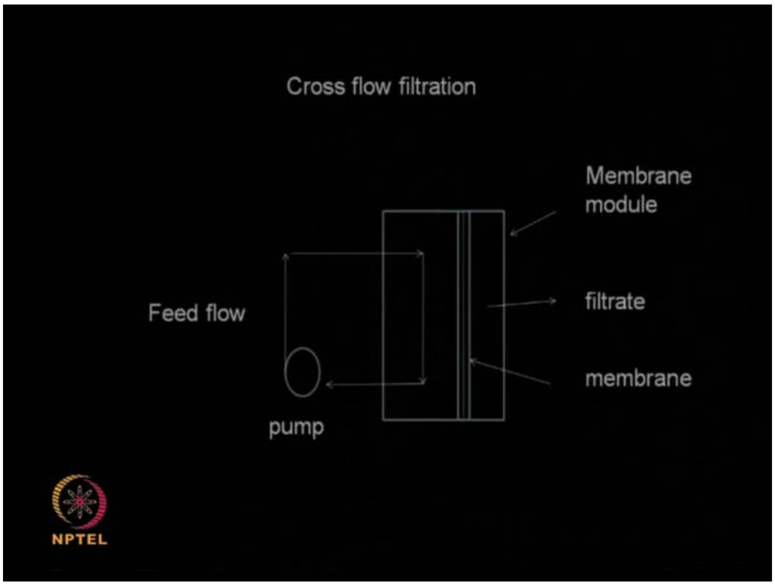

This is a typical picture of the cross flow filtration, if you remember how and you have the normal dead end filtration, where the flow direction is perpendicular to the membrane surface. Here you can see the flow direction is parallel to the membrane surface. So, that is why it is called a cross flow filtration. So, here you are not going to have any concentration polarization and boundary layer formed. So, we can have much longer filtration process, when compare to the dead end filtration process.

So, with a fouling also gets reduced, because your liquid is flowing parallel to the surface. So, the boundary layer is not getting formed, anyway you if there is a biofilling formed, it gets discharged or wash out or removed.

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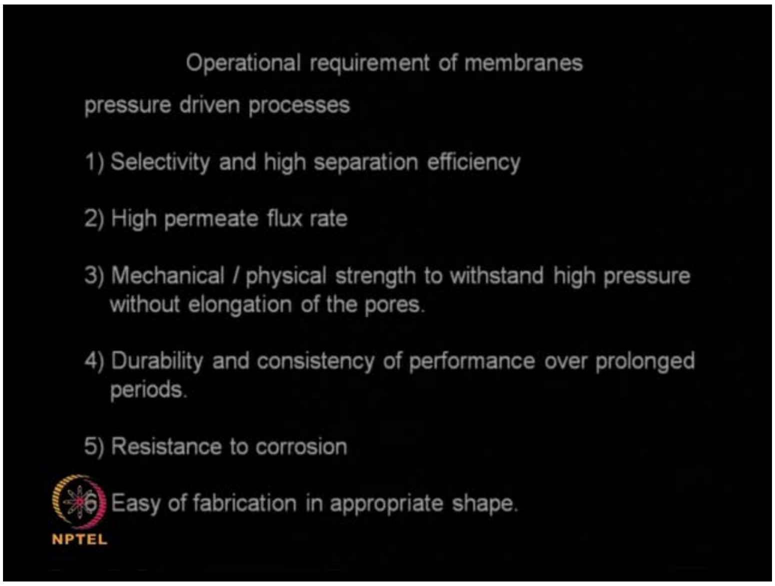

There are many operational requirements in a membrane process. So, you need to keep all those points in mind, we want to have very good selectivity, we want to have high separation efficiency. So, this is the fundamental point.

We want to have high permeate flux rate that means, the rate of filtration has to be very good. The membrane should have good mechanical and physical strength to withstand the high pressure continuously, you are operating at such high pressure. So, your mechanical strength should be quite high, the pore should not get elongated because, you are continuously applying a mechanical force.

Durable it should durable and the performance should be constant over a prolonged period of time, so that means, the performance should not vary with time. It should be resistance to corrosion that means, it should not corrode that means, whatever material you are filtering and the membrane material have to be compatible with each other.

It is easy to fabricate I mean it should not very complicated process and it should be appropriate shape, I may be using plaque placement brain, I may using tubular membrane and so on. So, it should be easy to fabricate of the shape, we want to have.

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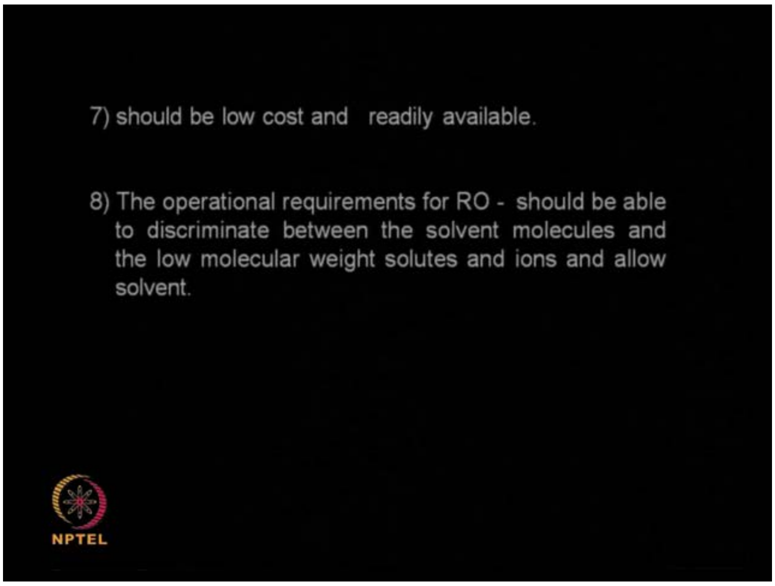

It should be a low of cost, cost is the most important thing and although we say should be of low cost, the cost of replacing the membrane is the most difficult and cost of replacing membrane is very very high. And so, the operating cost involves this cost and if you can reduce the membrane replacement cost or if you can prolong the membrane life, your operating cost will definitely come down. And it should readily available of course, this obvious.

If you take reverse osmosis membrane may are be are removing dissolved monovalent salts where, we are applying a very high pressure, it should be able to discriminate the low molecular weight solutes and ions and solvent. So, the solvent should be passing through the membrane whereas, these very very small ions or low molecular weight solutes should be retained by the membrane. So, it should have the differentiating capacity, because they are working at molecular sizes of solvents as well as smaller ionic sizes.

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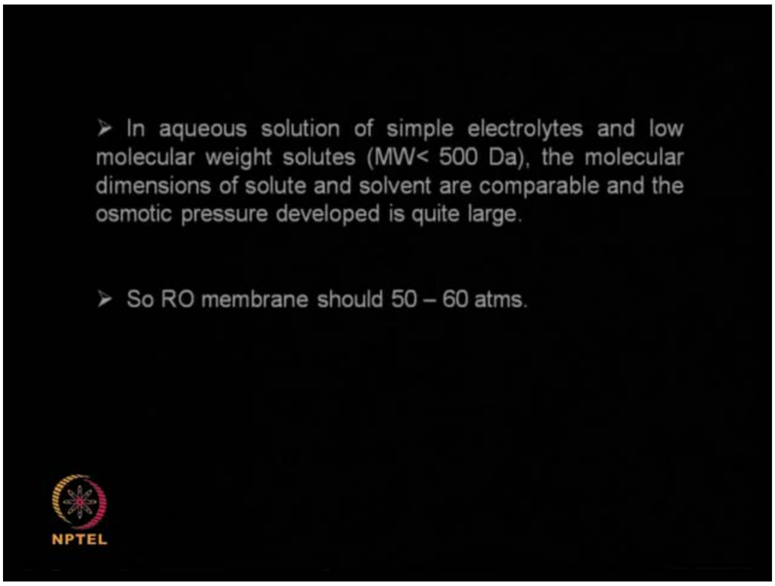

So, if you take a aqueous solution of simple electrolytes and low molecular weight material like a less than 500 dalton, the molecular dimension of the solute and the solvent will be comparable. So, you need to keep that point in mind. And now, reverse osmosis will be very very large. So, our reverse osmosis membrane should be operating at almost 50 to 60 atmosphere pressure.

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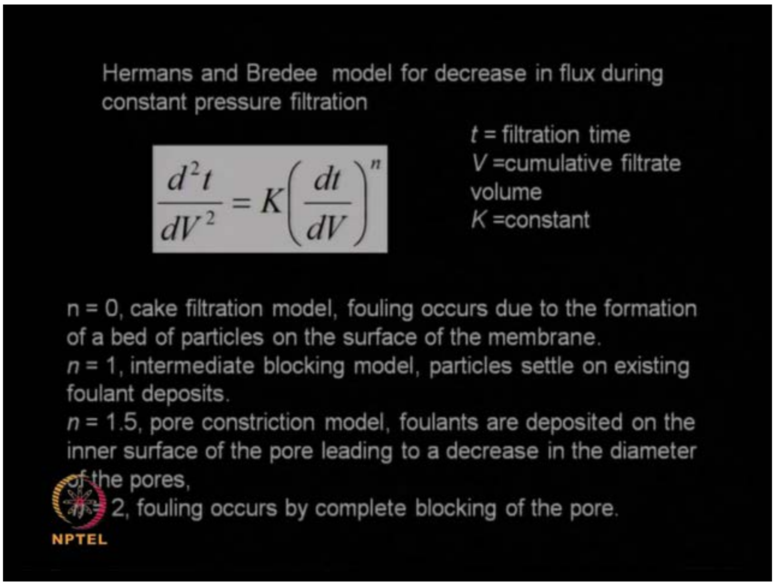

Now as you keep filtering or a as the membrane process keeps taking place, there is always decrease in flux over a period of time at constant pressure that means, we are applying the same pressure. But, still the flux will keep decreasing and them hermans and bredee have developed a model, which is given by this particular equation d square t by d V square, that is second derivative of the inverse of a d V and t is equal to K into d t by d V rise to the power n.

T is your filtration time, V is your cumulative filtrate volume and K is any constant, now n can take different numbers depending upon that type of assumption of type of a model, which we have in mind. So, if it is cake filtration model that means, fouling occurs due to the formation of a bed of particles on the surface of the membrane, then n is considered as 0. If n is 0 then what do, we say d square t by d V square is equal to constant is equal to K.

There is something called intermediate blocking model, where particles settle on existing foulant deposits that means, there is foulant deposit that particles start sidling in that case n is equal to 1. Then we have something called pore constriction model, foulants are deposited on the inner surface of the pore. So, as the foulant start depositing on the inner surface of the pore the diameter of those pores becomes smaller and smaller that means, it decrease weight time as the foulant start settle in down.

There we take n is equal to 1.5, now fouling occurs by complete blocking of the pore then n becomes 2. So, you see we can put different n values depending on the type of model or type of assumptions once takes into notice or 1 conceders.

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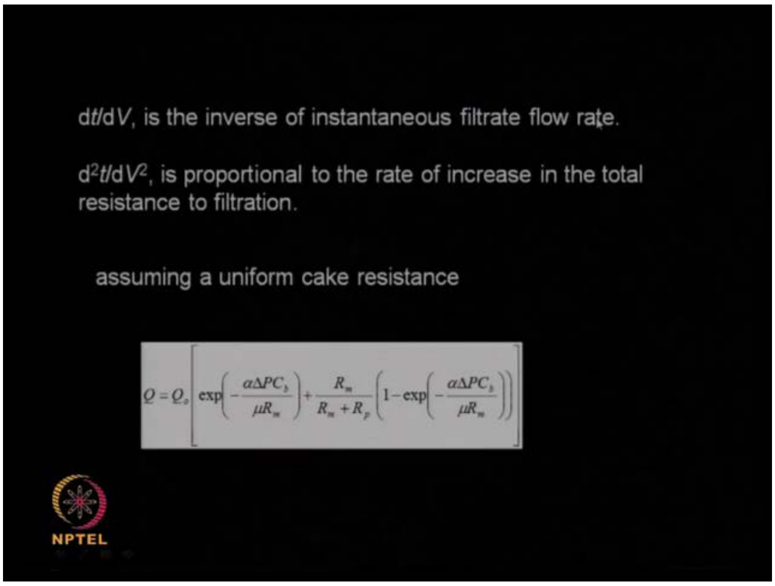

Now d t by d V that is on the right hand side, which we have is inverse of the instantaneous filtrate flow rate, because, V is the volume d V by d t is the filtrate flow rate, at d t by d V will be the inverse of that. Now d t square by d V square is proportional to the rate of increase in the total resistance to filtration, that is what is on the left hand side, that is rate of increase in the total resistance to filtration.

So, if you assume a uniform cake resistance then, we can integrate that equation and we end up with a equation like this with the exponential term. That means, the flow rate will keep uniformly decreasing, let us look at what each term is in the next slide.

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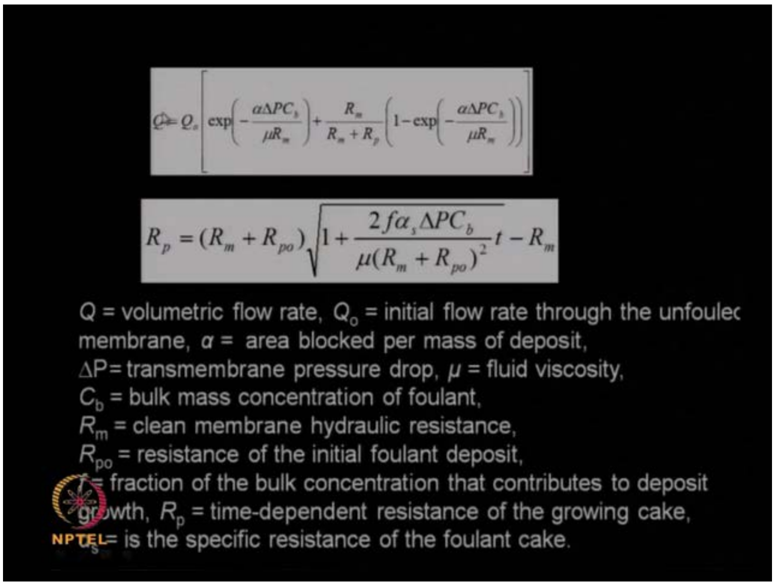

So, here you have Q equal to that is volumetric flow rate, Q not initial volumetric flow rate to the unfold membrane, there are exponential terms coming here. Alpha is a area blocked for mass of deposit, delta P is the trans membrane pressure drop, mu is you fluid viscosity. C b is the bulk mass concentration of foulant, R m is your clean membrane hydraulic resistance, R p not resistance of the initial foulant deposit. F is your fraction of the bulk concentration that contributes deposit growth, R p is the time dependent resistance of the growing cake and alpha S is the specific resistance the foulant cake.

So, you have a large number of parameters coming into picture resistance support by the deposit resistance of upward by your membrane material un cake resistance area blocked because, of the deposit and so on. So, this is how this flow happens as a function of time mean there is going to be some sort of a deposit. The deposit could be re s type, so the n could be ranging from 0 to 2.

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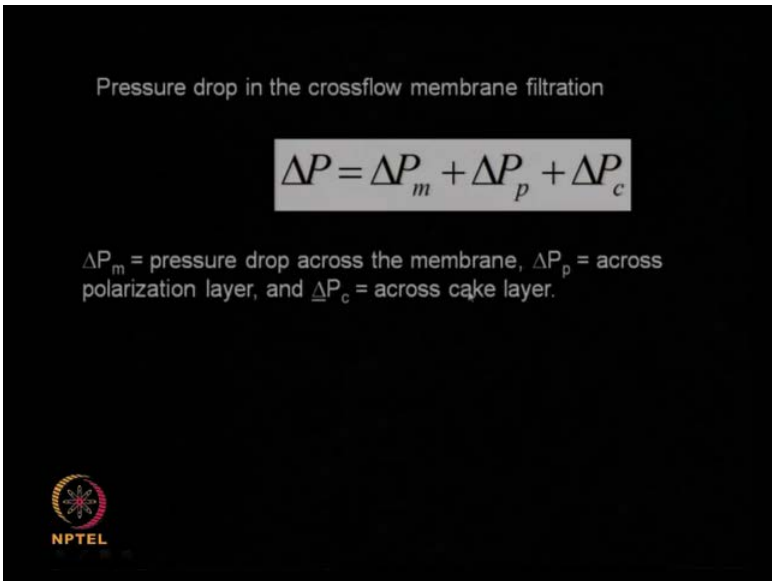

Now you take a cross flow membrane, the pressure drop in the cross flow membrane will be made up of 3 terms, pressure drop across the membrane material across the polarization layer and across the cake layer. So, you are having 3 pressure drops, which will add up to over all pressure drops. So, you need to keep that in to mind pressure drop, because of the membrane material pressure drop, because of polarization pressure drop, because of across the cake.

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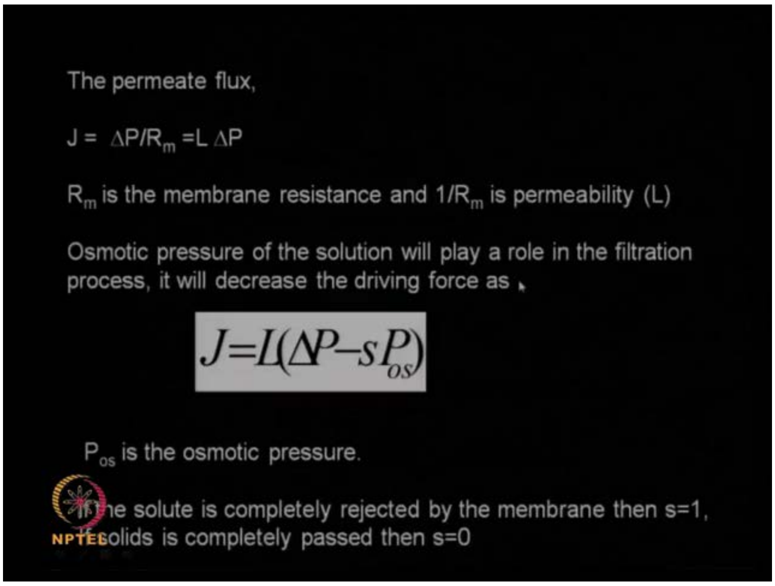

Now, the permeate flux that means, rate at which the liquid flows from the upstream to the downstream will contain 2 very important term. The permeability L or 1 by L is call the R m, membrane resistance and the delta P is the driving force the pressure. So, the permeate flux will depend upon the permeability of the membrane material and the driving force. Now of course, osmotic pressure is also going to play a role, osmotic pressure will reduce the flux, that is it will decrease the driving force do you understand.

So, you are filtering and there is an osmotic pressure, because the permeate has very low concentration of your solute. So, it is going to reduce the driving force. So, that is situation the driving force the will get change here. So, the flux will be equal to the permeability multi replied by delta P minus s P o s is the osmotic pressure and s can take a 0 or 1 value is the solute is completely rejected by the membrane.

Then s will be 1, if the solids or solute is completely passed then s is equal to 0, that means if solids completely move the other side, then osmotic pressure has no effect on the driving force whereas, the solute is completely captured, That means, on the downstream, you have pure solvent without the solute then, osmotic pressure will have a maximum effect, because s will take the value of 1.

So, s takes value of zero or one and it is zero if the solute or solid get completely passed. So, the effect of osmotic pressure is completely felt on the membrane process. So, the delta p gets decreased because of the osmotic pressure so, if s is equal to 1 that means, completely rejected, if s is equal to 2, that means the solid is completely pass. So, the s is equal to 0, what happens you have only L into delta P. So, the osmotic pressure is not felt whereas, s is equal to 1, you have delta P minus P o s, which is osmotic pressure. So, maximum osmotic pressure is felt in and the rate of filtration goes down.

So, we look at some problems later on this. So, the permeability varies depending upon the type of a membrane material we use. So, different membrane materials may have different L values generally in manufacturer provide just with the value for L.

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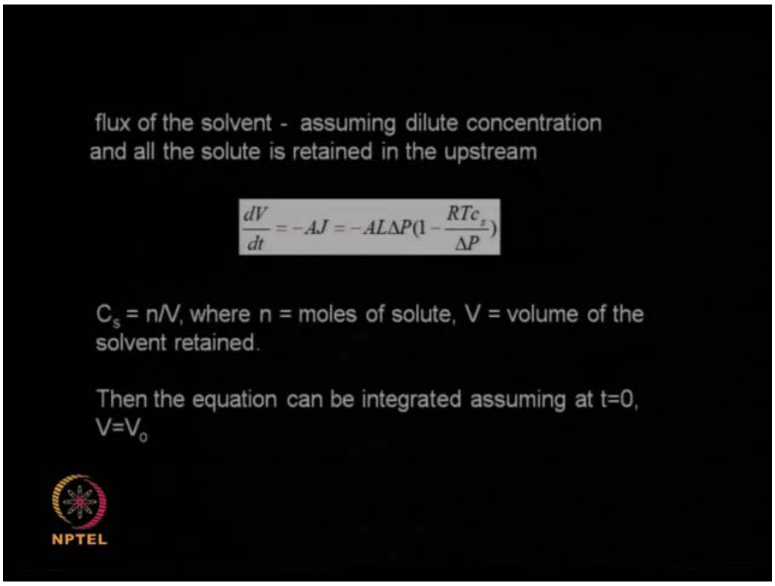

Now, look at the flux of the solvent will be d V by d t, that is the volume of the solvent retained that is equal to minus A J, J is a flux a is the area. So, this is given by J is given by L delta P 1 minus the osmotic pressure value here, assuming s is equal to 1 here, we will look at this osmotic pressure later.

And how to define osmotic pressure in terms of concentration based on mentors relation. So, will talk about that later, but for the time being will assume this equation can be integrated assuming at T equal to 0, V is equal to V 0 correct.

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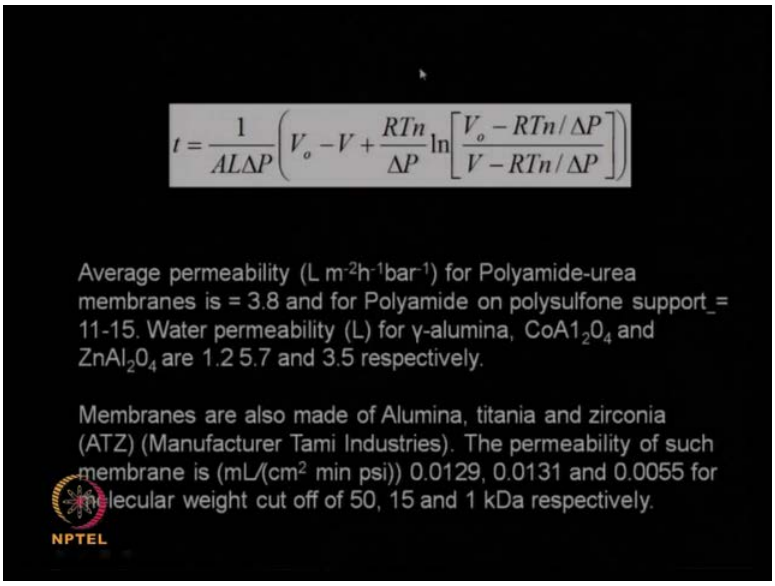

So, if we do that will end up with the relation like this, T is equal to 1 by A L delta P and. So, on actually we will talk about a relationship between concentrations of the solute dissolved on the osmotic pressure later. Now the average permeability that is look at the units liter per meter square per hour per bar, bar is the pressure, hour is the time, meter square comes out in because of the area.

For polyamide urea membrane is 3.8 and if you look at polyamide on polysulfone support, which are 11 to 15 water permeability for gamma alumina cobalt alumina and zinc alumina are 1.2 5.7 3.5. So, these numbers vary depending upon the type of inorganic materials you use. So, you can also make membranes with alumina, we talked about, so many polymeric materials p b d f and polyethylene, polycarbonate, polyacrylamide and cellulose, acetene and so on.

So, we can make with the inorganic materials. So, like alumina titania and ziconia. So, there are companies, which manufacture this type of membranes tami industries is the permeability of such membranes in terms of my m L per centimeter square minute p s i and is 0.0129 or 0.131 or 0.0055. For a molecular cut off a 50 15 and 1 kilo Dalton, the advantage of inorganic membranes are they can, which stand a temperatures that is the main advantage.

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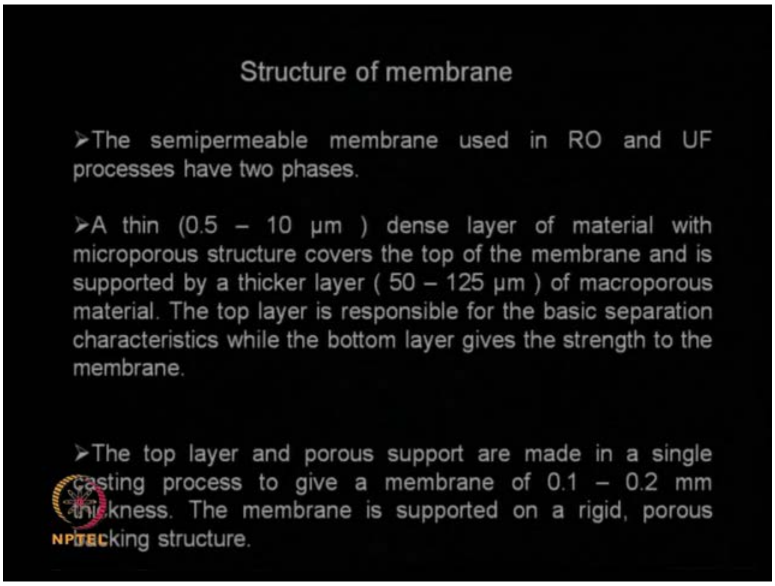

Structure of membranes so, the membrane will have 2 phases, you will have a thin dense layer of with microporous structures. So, this could be about 0.5 to 10 microns structure covers the top of the membrane and it is supported by a thick layer 50 to 125 microns of microporous material. So, the bottom gives the strength to the membrane, the top layer is responsible for the basic separation. So, the top layer maybe 0.5 to 10 microns. So, the bottom layer could be thick 50 to 125 microns.

So, you generally make it into a single casting process top and the porous support to give a membrane thickness of 0.1 to 0.2 mm depending upon type of membrane. So, later then, you support the membrane on a rigid porous backing surface.

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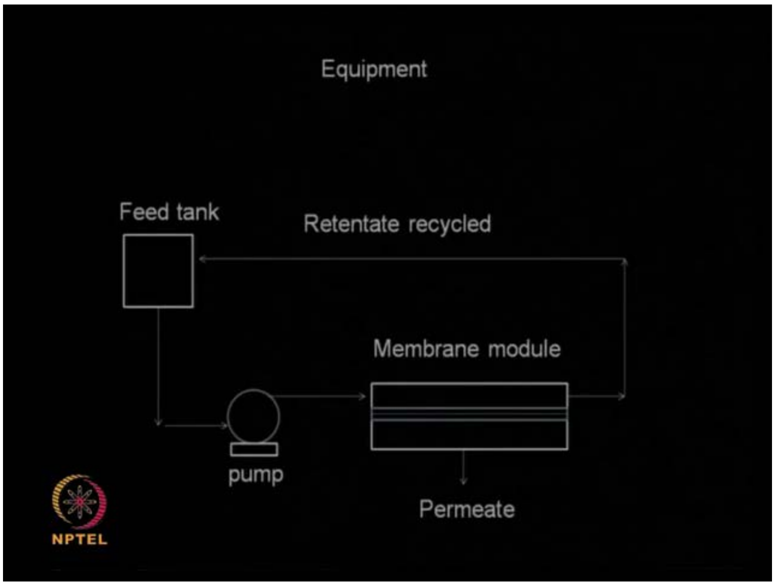

Typical equipment if you want to have an membrane, I may have a feed tank, I may have a pump, I may have the membrane module. So, the solution flows this is like a cross flow and then it comes back. So, there is a permeation taking place. So, if it is a concentration the aqueous liquid flows. So, this liquid going back is getting concentrated more and more whereas, if it is separating out is certain particles again the same thing happens in this process. So, this is a typical equipment for performing an membrane operation.

So, you will have a feed tank that is I am we will have as I explained before, we may have a pre filter to filter out suspended solids, we may have precipitator were, we may be adjusting p H precipitate, you are dissolves solids, we may have a tank where, we may be adding a biocide or a fungicide. So, that the liquid does not form a biofilm or bacterial layer on top of the membrane surface. So, all these are done so, those such smaller vessels are also incorporated in your flow diagram.

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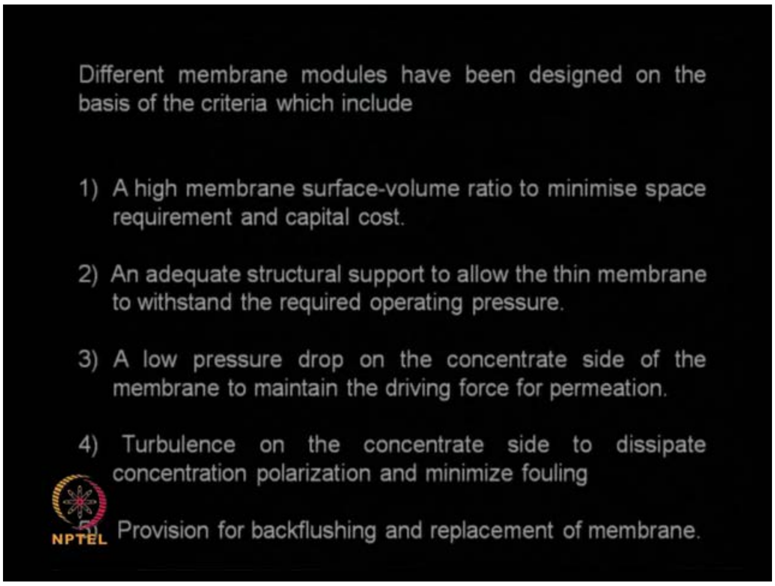

So, different membrane modules have been designed based on the criteria of your selection. So, generally our goal is to have a very high surface area to volume, why we are doing that, we want to minimize the space requirement and if you are minimizing the space requirement. We are minimizing the capital cost, we will have to have good structural support. Because, if the membranes are very very thin, we need a good backing structural support, if we are operating at very high pressure, otherwise thin membranes will just brake.

We want to maintain a very lower pressure drop on the downstream, that is on the concentrate side of the membrane. So, that to maintain driving force for the permeation, we want to have a good turbulence, so that we want to minimize fouling, we want to have minimize concentration polarization. We should have provision for back flushing and replacement of membrane.

That means, I should be able to after 1000 hours or. So, many 100 hours I should be able to back flush and remove the foulant, I should also have the provision for replacement of the membrane. Because, you may be doing back flushing many times, but after some time the membranes has been fouled. So, much there is no hope of recovering of it is performance. So, we may have to replace membrane, so it has to be facilities for performing this type of job as well actually.

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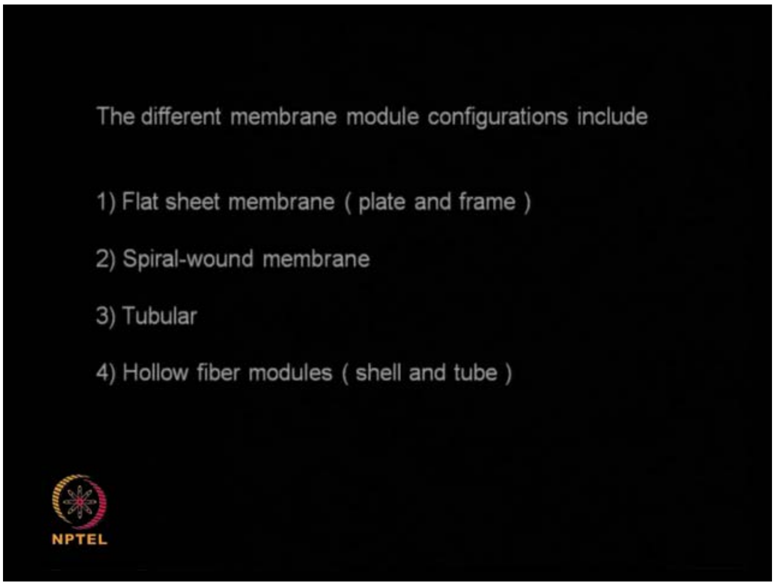

So, different types of membrane modules are there, the flat sheet membrane, that is like a plate and frame, you have a plate. So, the membrane material is in the form of a plates and then you have frame. So, the frame holds the flat plates, you can have a spiral wound membrane that means, the membrane is wound like a spiral, you can have a tubular membrane.

That means, a long tube in this the surfaces is made up of membrane, the liquid flows inside, you can have hollow fiber modules that means, it is like a shell and tube heat exchanger. You can have lot of hollow fibers and membrane process takes place, because of the flow in the inside.

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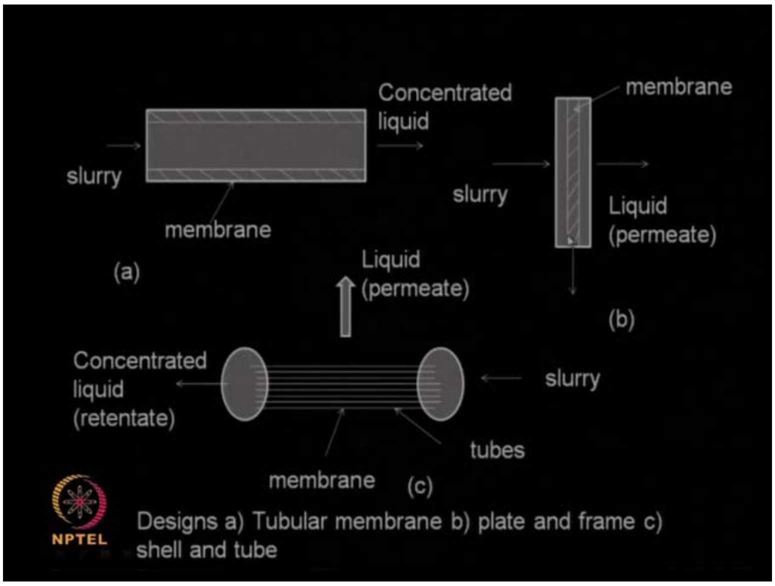

So, these are just some pictorial representation of different designs of a membranes. So, this is a tubular membrane. So, it is a tube and the walls are made up of the membrane material. So, the slurry flows and the liquid or the solvent may permeate out through the surface of this tubes. So, in this side you may end up having concentrated liquid area, this a plate and frame type of design, you know you have the membrane, you have the frame, which holds the membrane.

So, the flow is happening here, liquid is flowing here. So, if I want to increase the surface area, I may have many plates and many frames stuck together, it is very simple here, If I want to replace the frame, what do I do. And if I want to replace the membrane, I will just remove these frames, I will remove the sheet of membrane, I will put another sheet of membrane.

So, job is quite simple. So, increasing the surface area, I will put many plates and frame that is the way increasing surface area of the membrane process. The third design is like a shell and tube, so you have may tubes of membranes. So, your liquid may be flowing here and they get a distributed along the tubes and on the other side, you may have a concentrated liquid flow here. And your solvent or water may be flowing out of the solution, so this is another design.

So, if you want to replace a tube you need to open up this heat exchanger take 1 of these tubes, which mitabin foul beyond use or mitabin physically mechanically damage. Then you can put another tube here and carry out your job. So, that is another way of looking at this type of a shell and plate type of design actually.

So, you have large designs possible and especially, if you are working with the polymeric material, you will be able to cast different types of a membrane designs that is the main advantage of working with the polymeric material whereas, if you are working with the inorganic material like ceramic and so on. It may be quite difficult to cast or prepare those type of a material of required shape or size perform in, which you would like to have it.

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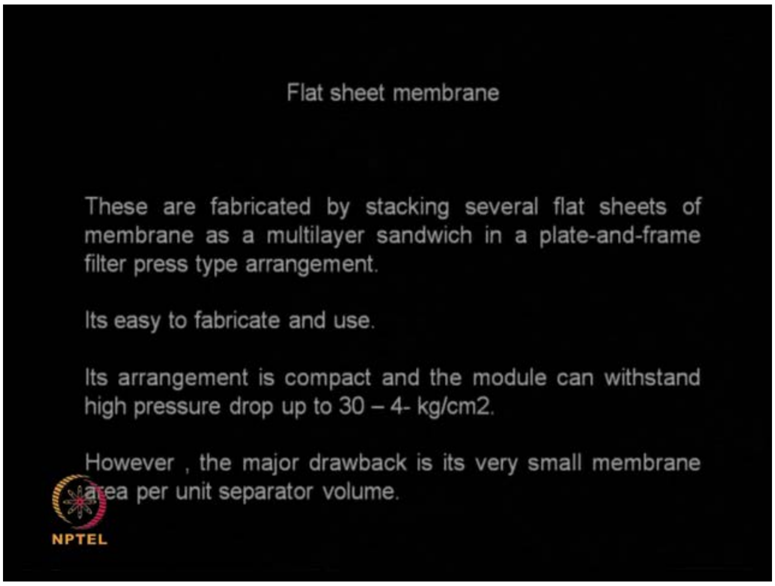

Flat sheet membrane, lets look at these flat sheet membrane, they are used in plate and frame type of design. So, we can have multiple layer of sandwich of a different types of membranes stuck together, it is like a filter press, so it is easy to fabricate. So, we can compactly design it and structure it can even work under quite good pressure drop, here we are talking in terms of 30 to 40 kg per centimeter square. Main disadvantage surface area is small that means, I need to have several plate and frame designs to achieve the require surface area.

So, that is the main disadvantage with the flat sheet membrane, although I can just make the membrane in 1 design large sheets, I can cut the sheets to the desired size of my frame and bolt it to the frame. So, the fabrication and setting up of my membrane unit is easy by the major drawback my surface area per separator volume will be very very less.

So, it is a not good enough, I may have to put several stacks of a plate and frame design, that is the main disadvantage of flat sheet membrane.

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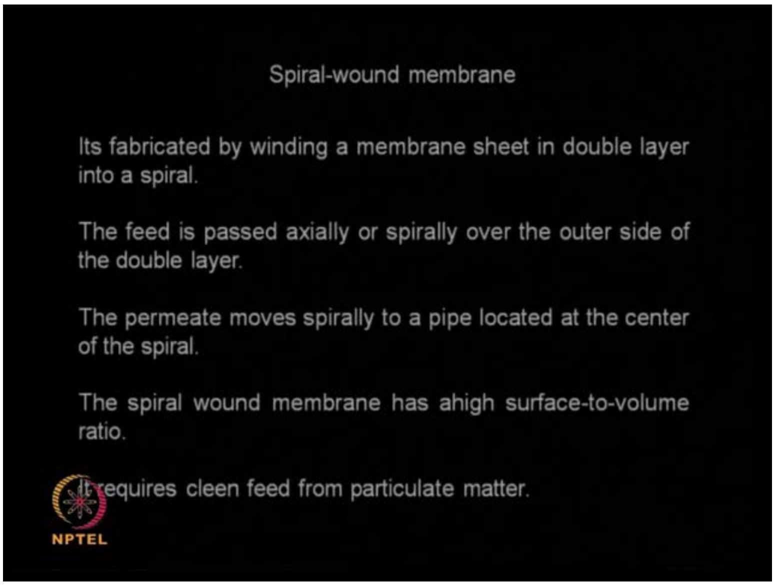

And another design is your spiral wound membrane, so how do you do it, you have a fabricated wound of a membrane sheet in double layer into a spiral. So, you get it like a spiral, the feed is passed axially or spirally over the outer side of the double layer. So, the permeate also moves spirally to a pipe located at the center of the spiral, so with liquid flows in a spiral manner.

So, we get a very large surface to volume ratio, but 1 thing you have to careful about is your feed has to be quite clean it should not have any particulate matter. Because, as the liquid flows in a spiral manner, if there are particulate matter, it may damage the membrane surface.

So, the spiral wound membrane advantage is it will have very large surface area to volume, when compare to your flat sheet. But, be careful that particulate matter does not spoil or damage the entire spiral whereas, if there is a particulate matter in flat plate membrane, it may be damaging only one small area of your surface. So, this is what spiral wound membrane is all about actually.