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Lecture - 22 Membranes (Continued)

We will continue with the Membrane processes, as I mention membrane market is very big, globally it is become very fashionable, and it is operated at atmospheric temperature. So, membranes are widely used in water treatment, purification, removal of salts, removal of proteins, so both for purification as well as, recovery or concentrating and various different applications. So, several types of membranes, varying from inorganic material of construction to synthetic polymers to natural polymers and to composites and so on.

And there are different types membrane processes; ultra filtration, microfiltration, nano filtration, reverse osmosis, dialysis, electro dialysis, pervaporation and so on. So, wide range of applications, it is going to replace as time proceeds many of the traditional chemical engineering processes. So, we will continue today, as well on the Membranes the applications and varies the operating principles.

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If we remember this particular slide, we talked about the concentration, polarization that happens because as the solution flows perpendicular to the surface of the membrane, there is a buildup of concentration of the solute and the upstream near the wall of the membrane material. So, the bulk concentration of the solute, will be much lower than the concentration near the wall and sometimes these values may be 50 percent or 60 percent or even much larger than the other.

And their governing equation for this comes from the fix law of diffusion. So, you have the flux, flux is the amount and that is flowing, that is amount of solute that is flowing per area per time is given by the diffusion coefficient D and d c by d x, d c by d x represents the concentration gradient along the distance. So, x is the direction along the flow and D is the diffusion coefficient the units are generally, centimeter square or foot square or millimeter square per time could be per second, per minute and so on.

Now, what are the boundary conditions, at x equal to 0 that is very near the wall in the upstream side of the membrane, concentration will be C s and at x is equal to d, d is your boundary layer this is equal to C b. So, we have these two boundary condition, then it is very simple for you to solve. Now, this boundary layer, as it is call here this depends on several parameters a typical chemical engineer can tell you, what are the varies parameters one it is depends, it depends on the on the liquid properties like viscosity, the density and the surface tension.

And then it depends on the flow of the liquid near the wall, if the flow is turbulent we are going to have a smaller diffusion distance or boundary layer the flow is very, very low we are going to have very large boundary layer diffusion thickness. Like last class I mention that we can create turbulence a near the wall. So, that you can make the boundary layer much smaller or we can even have cross flow; that means, you can have the solution flowing parallel to the membrane plate, rather than flowing vertically to the membrane plate that way we can have much smaller boundary layer or boundary thickness.

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So, if we solve that equation you will get a relationship for the flux in terms of a D by d. Now, D by d is call the mass transfer coefficient, logarithm of C s by C b. Now, this C b is the concentration in the bulk and C s is the concentration near the wall because of the concentration polarization.

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Let us, look at a simple problem. Imagine I am performing an ultra filtration process and the rate the process is 2.6 into 10 power minus 3 centimeter per second, the solution concentration is 0.44 weight percent, the diffusion coefficient for the solute is 9.5 10

minus 7 centimeter square per second, you know that they units for the diffusion coefficient is distance square per time, not forget that and the boundary layer is like this. What will the concentration at the surface of the membrane in the upstream side due to concentration polarization.

So, this equation you substitute for D that is your diffusion coefficient, you substitute for boundary layer, thickness small d and then the rate is given that is on the left hand side. So, if you solve that you will get C s by C b equal to 1.63; that means, if C b is 1 that is the bulk concentration is 1 C s will be 1.63; that means, the concentration at the wall is 63 percent more than the bulk that is a big number.

So, because of this concentration polarization because of the buildup to the concentration sometimes the rate of filtration sussed out because there is a buildup of concentration in the upstream. So, you can see how much the concentration polarizations go into affect, your filtration process. Now, if your boundary layer is very, very small; that means, boundary layer thickness is very small, it comes in the denominator. So, this becomes small your rate will pick up. So, that is our main goal to increase the, I mean the to decrease the boundary layer, conversely we can increase the diffusion coefficient then also your J can be made much larger.

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The permeate flux, is given by a relation simple relationship J is equal to L delta P, L is the membrane permeability delta P is your driving force that is the pressure. Now, there is going to be osmotic pressure, which will decrease this driving force. So, in the presence of osmotic pressure what will happen the J will be equal to L into delta P minus S P o s, P is your osmotic pressure and S can be 0 or 1, if the solute is completely rejected; that means, if the solute just passes through the membrane then S will be equal to 1; that means, the osmotic pressure will have an effect.

If the solute is completely passed then S will be equal to 0, if the solute is completely rejected by the membrane then S is equal to 1. So, if the solute completely goes through the other side then; obviously, that is not going to be any osmotic pressure that is coming in the reverse direction but if the solute is completely rejected then; obviously, the concentration of the solute in the upstream will be much higher than the concentration of the solute in the downstream. So, you are going to have a osmotic pressure taking place. So, that will decrease your driving force delta P here.

So, osmotic pressure plays a very important role, in reducing the driving force and the property of the membrane process, determines this particular reduction in the driving force. So, if the solids are completely passed then s will be equal to 0 because there is not going to be any buildup of osmotic pressure. If the solids are completely rejected; that means, the upstream concentration of the solids or solute is much higher than the downstream concentration of the solids or solute then s will be equal to 1 then you will have maximum osmotic pressure effect on the driving force. So, the driving force gets reduced.

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Let as look at a very simple problem. Now, we are trying to do your purification using a membrane, the solute concentration is 0.1 mole you are applying a pressure of 5 atmospheres the reaction be temperature of the process is 25 degrees. Now, if the solute is completely rejected; that means, the filtration process is, so efficient that in the downstream there is no solute, only pure solvent will be flowing and the upstream you have the complete solute.

So, if you remember s will be equal to 1; that means, you will have maximum effect of osmotic pressure in the pressure process. So, equation becomes J is equal to L delta P minus P o s, P o s is your osmotic pressure. So, you will have P o s decreasing your driving force here because solute is completely rejected. Now, how do you calculate P o s before going to that particular relationship will try to understand what is osmotic pressure and why does it arise and so on actually.

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Now, imagine you have a chamber, like this and there is a membrane here, we are put in brine on one side; that means, it contains a salt, which a salt water and on the other side we here pure water, this is at time equal to 0. Now, what will happen water will have certain vapor pressure, brine will have lower vapor pressure because we have salt which is dissolved in water. So, as you dissolve salt there is a decrease in the vapor pressure. So, the brine vapor pressure will go down, water pure water vapor pressure will be high.

So, what will happen there is an osmotic pressure. So, the pressure because of this water will push it and then water will enter here, to the membrane understand. So, what will happen this level will be higher, this level will be lower. Now, this difference is call the osmotic pressure. So, this difference depends upon the concentration of the brine solution, understand and the operating temperature. Now, if you want to make that water not to go from this side, to this side what do, we do we apply a pressure which is equal to the osmotic pressure.

So, by applying this pressure, we are forcing the water from the brine to the higher this is call the reverse osmosis. So, if you want to force water from a brine solution to a very dilute solution or to a pure water, we need to apply pressure much higher than the osmotic pressure, that is the principle of the reverse osmosis.

Under normal circumstances if we have a salt solution and if we have pure water solution, pure water and we have a membrane, the pure water will diffuse into the salt solution because of the osmotic pressure because of the decrease in the vapor pressure of the brine, due to the presence of salt. So, by applying that equivalent amount of pressure and more, we are driving pure water from the salt region into the pure water region.

So, this portion will get concentrated and concentrated with salt and finely at some point if the pressure you have to apply will be, so high that you need to discard this particular salt water, and this is the principle in which even desalination of salt water works, there are now, many places globally where pure water is produced using the desalination of a seawater, especially in midlist many countries places where we cannot have bore wells, there reverse osmosis is used for getting pure drinking water form seawater.

So, you apply a very large pressure, the pressures are very high could be even 100 bar. So, that is the main bottleneck RO type of systems, the pressures will be very high. So, your membrane system should be able to withstand there and as time goes the concentration of the brine solution increases. So, much you need to discard that brine solution and then you need to take fresh seawater. So, when you discard the brine solution you are creating environmental problem because that brine solution is. So, concentrated with salt nothing can survive, there that is a main problem actually.

So, RO system has one big environmentally sure that is how do you discard this brine solution, without causing any damage to the flora fauna around actually. Next point is the operating cost; the membranes are very, very expensive. So, from time to time you need to replace the membrane and put in fresh new membranes. So, the membrane cost is also very high in RO systems, but then if you do not have drinking water, if you do not have ranges and lakes then you need to resort to this particular technique.

RO membranes are also used in an industry at the end of the waste water treatment, if you are interested in getting portable water from a little bit of effluent; that means, the effluent might not be very toxic effluent, but it may be slightly undrinkable. So, portable water is also prepared in RO membrane.

So, you may have a ultra filtration membrane a priori and then finely you may have a RO membrane and then the water can be recycle and taken inside for gardening and so many other purposes actually. So, that way RO has become very, very important, now a days because if you are thinking about 0 discharges in industrial setup then this is the final ultimate solution. Now, let us go back to our old r o system.

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In reverse osmosis the pores sizes are very, very small. You can see the sizes 0.0001 micron. So, generally it permeates only water. So, it does not allow salts and low molecular weight material to permeate through. So, why do we call reverse osmosis as I mentioned in the previous slide, we are applying a pressure in the opposite direction to the osmotic pressure, that is why it is called reverse osmosis.

So, in the normal osmotic pressure, the solvent will diffuse from the low concentration to the high concentration side whereas, in reverse osmosis, the solvent will the fores from high concentration side to low concentration side. So, the pressures as I mentioned before can even be 100 bar here.

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So, it is very applicable for low molecular weight product such as, salts desalination of seawater, sugars, organic acids from aqueous solution, which used in food and dairy industries to concentrate fruit juices because if we have fruit juices we cannot go to distillation. Distillation will spoil the flavor and the taste of your food juices, we cannot go to solvent extraction because there could be residual solvent left behind and the solvent could be toxic for a consumption.

So, the best approach is using reverse osmosis. So, it can be used for fruit juices, it can be used for vegetable juices for milk. Now, if you look at nanofiltration. Nanofiltration is much, much finer when compare to say micro or ultra, it is almost similar to reverse osmosis, but the membranes are slightly more porous and it can be used for separating molecules up to 500 Dalton. So, in nanofiltration we can have still some molecules passing through, but in RO you are not going to have any compounds passing through only the solvent passes through.

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So, the solvent molecules pass from a region of low concentration to the region of high concentration. In osmosis what happens, driving force for the flow of solvents is the difference in the chemical potential. So, we have a difference in the vapor pressure. So, there is a difference in the chemical potential that is what is call the osmosis. So, when it reaches in equilibrium the chemical potentials have to be balanced on the both sides, all the osmotic pressure needs to be balanced on the both sides.

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So, the equation for the osmotic pressure is given by the vant hoff relation that is call the osmotic pressure is equal to R this is your gas constant, T temperature in Kelvin, C is the concentration of the solute per meter cube. Actually, this is a simplified version of the equation because; you will be having logarithm and so on actually.

This is generally valid for dilute solutions please remember that is why we got a very simple a priori equation otherwise, you will have logarithm. When we have very concentrated solutions, actual osmotic pressure will be where less. The ratio of the actual osmotic pressure, to the calculated value is called the osmotic coefficient or also it is called the corrected factor osmotic correction factor.

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So, if you have ionic solutes you are going to have some dissociation taking place ions, more ions may be formed starting from single, neutral, molecule. So, we need to consider the number of ions that are produced also. So, you have the osmotic pressure equations slightly modified like this n into, R into, T into, C n is called the vant hoff factor number of ions produced when the solute molecules completely dissociates.

Now, if you have more than one salt. So, salt one can have, one concentration salt two can be another concentration salt three can be another, then you are going to have summation of pressure cost by each of the salt. So, the total osmotic pressure will be the summation terms here, and the c here can be concentration one of salt one then you can have plus concentration two of salt two plus concentration three of salt three and so on actually. So, it is an additive property, if you have more than one salts. So, this particular term will lead to a decrease in your driving pressure.

Purification is performed in a membrane system. Solution concentration is = 0.1 M. Applied pressure is 5 atm. Temperature = 25°C.If the solute is completely rejected what is the effective pressure in the process. $J=L(\Delta P-P_{os})$

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Now, if you go back your old problem, we are talking about the solute completely rejected. So, what the s here became one. So, J will be equal to L is your permeability, delta P is your pressure, P o s is your osmotic pressure. Now, P o s is given by RTC, C is given by 0.1, T is given by 25 degree centigrade; that means, 273 plus 25 298 Kelvin r is your gas constant. So, that will give you the P o s. So, you know P o s, your pressure may be 5 atmosphere, but because there is a negative term and P o s comes in your total driving force gets decreased. So, your rate in the membrane is decreased because of this r into 298 into 0.1. So, this is how you calculate the rate of a membrane purification.

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There are different types of membrane configurations which I mentioned yesterday we can have a flat sheet membrane that is like a plate and frame design, we can have a spiral-wound membrane; that means, the membranes, material is wound like a spiral. So, the flow also takes place in a spiral fashion, we can have a tubular membrane; that means, it is like a tube and the tube is the walls of the tubes are porous, we can have hollow fiber modules it is like a shell and tube type.

So, all these types of designs are possible, then whole idea is to increase the surface area of the membrane per unit volume minimal. We go to flat sheet membrane the surface area per unit volume is not is low whereas, if we take the other membranes, the surface area is much, much higher.

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So, these are simple schematics of a these different types of membranes. So, you have a tubular, you have a long tube, the walls are made up of membrane material, as I said it could be a organic, material it could be a natural material, it could be a composites. So, your slurry flows in, and the solvent flows out through these walls and you may be getting concentrated liquid. We look at this; this is a plate and frame design. So, surface area per volume is low here, you have the membrane here slurry flows in. So, if I want increase the surface area I will put many, many plates that is the whole idea of this.

We look at the shell and tube type of a situation, we have lot of tubes this is like a heat exchanger shell and tube heat exchanger, you have lot of tubes. So, you have a header here on the side you have a header here on the side. So, your slurry flows in it gets distribute into varies tubes and then finely the concentrated liquids again are collected from all these tubes into the header and then removed. So, this is a shell and tube design. So, if the one of the tubes gets spoiled, we will open it, we will remove the tube we will put in another tube. So, this is how you perform the process actually.

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Tubular membrane. So, it is called a shell and tube module, it consists of several tubes of membranes, bounded at each end that is are header and again on the other side also you have a common header. So, the slurry flows in gets distributed and then the permeate passes through the wall because the membrane walls or porous. So, the retentate passes out on the other side again they are collected at the header and then removed actually.

So, what do you use, if you have very high viscous feed material or you can have mostly high viscous feed material is in either food products or is it in fruit juices example is like a tomato puree, where you want to concentrate it to a very high degree. So, the water will pass through the walls and come out and the tomato puree which is very highly viscous will flow through the entire tube.

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Hollow fiber, we have the hollow capillary fibers of membrane, packed into a shell and tube arrangement. So, you get a very high surface area per unit volume. Here the feed must free from particulate matter otherwise, what will happen if there are any particulate matter it will go and get stuck to the hollow fiber, it will do a mechanical damage to the fiber or it will even prevent your filtration process.

So, what do, we may have a here pre filtration facility. So, you may have a ultra filtration in the beginning and then you may go to your hollow fiber membrane. So, if you have a ultra filtration, then in the hollow fiber the pressure is applied on the inside of the fibers. So, that is the driving force, but if it is in RO process then the pressure is applied on the shell side; that means, it is applied on the outside.

Hollow fiber is preferred in dialysis because we are looking at very, very large surface area and we do not want to apply big driving force also because we are dealing with the human system, we the driving force is not large like an industrial scale. So, the other idea, other way of increasing flow rate or the filtration rate is to increase the surface area. So, hollow fibers are preferred in such a situation. (Refer Slide Time: 26:50)



Micro filtration. Now, this resembles conventional filtration, just like a normal filtration process which we study many, many classes back. So, the filter medium is a porous membrane. So, it can be used for filtering particulate material. So, big material it can be used for suspended solids. So, it cannot be used for dissolved solids. So, microfiltration us almost like a early stages, instead of a normal filter cloth, we can even resort a microfiltration. So, dissolved solids cannot be separated in microfiltration.

So, we can be used for harvesting microbial cells. So, I am interested in intracellular material I can use a microfiltration from fermentation broth, I can use it for separating blood cells and plasma from whole blood. So, what type of configurations do you adopt in microfiltration, we can go for plate and frame, we can go for spiral wound, we can go for hollow fiber module. So, all these types of designs are possible in microfiltration.

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So, we have thin and porous filter medium or membrane supported on rigid supported like a normal filtration system. So, we can have synthetic organic molecules, like polypropylene or PTFE we can have alumina or zirconia and they have to be made chemical resistance if you are processing, chemically actor solutions. The most important points we need to consider is the wettability because the membrane should not be very hydrophobic otherwise, wettability will be very poor.

Adsorption characteristics will the membrane material adsorbed salts because if it absorbs in starts swelling, then that will be a problem. The chemical and mechanical stability, it should be chemically inert otherwise we do not want any reaction taking place with the solution and a membrane, they should be mechanically stable because we are applying pressure, sometimes you may have solids, which may be causing attrition to the membrane surface.

So, it should be mechanically stable. In most of the membrane process, the cost of the operation is determined by the cost of replacement of the membrane actually. So, membrane cost is the highest which makes or breaks your operating constant membrane process.

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So, here we can allow even macro solutes, but not colloids and suspended solid particles in the size range of 0.1 to 10 microns. So, the flow of solvent and the solute is because of the convection through the pores. So, it is like a normal a settling or filtration process and the pressures are low 1 to 2 bar only. So, we can operate in a normal flow mode; that means, the solution flowing perpendicular to the membrane, surface or it is also called dead end method or it can be cross-flow mode.

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The normal mode the feed is entering perpendicular to the filter medium. So, as the filtration progresses you are forming a cake. So, the cake formation will decrease your rate of flow, we talked about cake can resistance of the cake and so on long time back. So, this is a typical place where those issues will come into. And if you are using a for the separation of biomolecules or microbial cells the cake could be compressible as well.

So, a cake is compressible. So, there is going to be a non-linear relationship of the flow with the pressure drop, I hope you can recall those equations which we talked about a long time back. So, the flux here will depend upon the driving force delta P divided by r m plus r c, r m is the resistance of the afforded by the membrane and r c is the resistance afforded by the cake.

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The pores in the filter medium are small. So, the filter medium also will afford some resistance unlike the normal filtration, in a cloth type of filter the resistance afforded by the cloth is much, much smaller than the cake. So, we generally neglected, but when we are talking about this type of a filtration, microfiltration the pores are slightly smaller. So, we need to consider that also we cannot totally rejected keep that in mind. Now, the resistance afforded by the cake if you recall our old Darcy's law, this is a equation and delta P raise to the power s because of the compressibility of the cake A is your area.

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So, alpha is your specific resistance, w is the slurry concentration dry solids per meter cube of filtrate, s is the compressibility. So, 0 for incompressible or 1 for perfectly compressible. So, you can have a values varying from 0 to 1, V is your total volume of the permeate, n is the viscosity of the permeate, A is the area of the membrane. So, because as I said the membrane material will also afford some resistance because the pores are much smaller and compare to your traditional cloth or c u or metal type of filter you need.

So, we need to keep that also here. So, this is a typical equation if you recall from our very early classes, the flux is given by all these parameters. So, s can vary between 0 and 1. So, if it is incompressible this term will completely disappear, if it is fully compressible you are going to have s is equal to 1 also. So, the s can vary between 0 and 1 depending upon the compressibility of your cake.

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If $r_m << r_c$ then the total volume of the permeate that will pass through the membrane of area A is

$$V = A \Delta P^{(1-S)}$$

If S = 1 then the flux through the membrane is independent of pressure drop.

In many cases $\alpha, W, \ \eta \,$ and the total flow rate through the membrane JA are constant.

An advantage of microfiltration is --- frequent fouling of membrane due to deposition of solids

So, of course if we assume that the r m that is resistance afforded by your membrane material is very, very small, we can neglect that. Now, in many cases alpha W eta and the total flow rate, through the membrane are always constant actually, we can assume. So, once the flow rate starts decreasing because of the compressibility of the cake may be you will stop your filtration, you may do a back flushing or you may do a dismantling and removing the cake that is formed and again you will restart your membrane.

This is like a traditional filtration, that is regenerating your membrane filtration process. Now, the disadvantages microfiltration is frequent fouling. So, you are going to have fouling because of the settling of the cake. So, we need to from time to time do a back flush and remove that cake that is formed. So, you filtration process, back flushing process that is cake removal again filtration process back flushing and so on actually. So, ideally you would like to have a very long filtration, without actually doing a back flushing which will slowdown your overall rate.

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So, once the pressure keeps increasing slowly and slowly because of the deposition of the cake the membrane needs to be whether cleaned or replaced sometimes the membrane, gets totally compacted. So, even if we do a cleaning you will not be able to recover it is permeability. So, at that point you may have to replace your membrane material.

Now, increasing the area of membrane twice decreases the flux by half but total volume of the filtrate will increase four times but increasing the area of the membrane will reduce membrane replacement cost by half. So, the question is do a have very large area membrane. So, if you want to have very large area membrane; that means, by capital cost of the membrane setup will be high, the cost of the membrane itself will be high.

But, then replacement cost, will go down; that means, I will be able to do the filtration for much longer periods of time; that means, the operation; that means, the planed will be running uninterrupted for much longer time. So, you need to balance between should I have a big membrane assembly with the, large surface area membranes or should I have smaller assembly; that means, my capital cost will be less, but then I will be doing the membrane cleaning or membrane replacement quit frequently; that means, my process will get disturbed much more.

So, can I afforded to do that or do a need a big planned where I will have, much larger surface area membrane then I will be running my planned undisturbed for much longer

periods of time. So, you need to balance between, your real process and whether you can have more stop start, more stop start or you would not have an interrupted type of a operation. So, that all depends upon what is the product you are manufacturing, what is the fermentation that is taking place, what is the fermentation time and so on actually.

So, if you are fermentation, broth can be stored in a tank, intermediate tank and then we can do a filtration in membrane process. So, that your fermenter is not disturbed when you stop and start your membrane filtration, then you may be able to afford to have a smaller membrane unit with the lower surface area.

Whereas, you cannot afford to store your material after fermentation, but you want to quickly do a filtration because may be the biomolecule or a bio product is very sensitive to the salts present or the toxin present, that you want to quickly filter and recover then in that case you will not be able to storage, but you will not be able to have too many start and stop. So, in that situation you will like to have a large membrane assembly; that means, you will have the larger surface area membrane as well.

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So, the buildup of solids on the membrane can be minimized by installing a depth filter upstream. So, we can have a pre-filter or a depth filter, I talked about depth filter also before. So, that depth filter will remove a large amount of quantity of yours suspended solids and then we can go to a membrane. So, the buildup of k in the membrane will be much less.

Another disadvantage of microfiltration is concentrated slurry and not a dry cake. So, you will not get a dry cake, the pressure you are applying is only 1 to 2 bar. So, the buildup of solid will be more slurry, rather than a dry cake; that means, the slurry again needs to be process if you want a dry cake; that means, we may have to take it to a oven or a dryer, where we remove all the solvent or water and then you get the dry cake which can be disposed out.

As the filtration takes place, you are also going to have the increase in viscosity, that is another problem in a microfiltration. So, the viscosity of the slurry as the solvent is removed is going to increase. So, it will retard your permeation or membrane filtration process.

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So, these are some of the disadvantages of this type of a filtration, microfiltration. So, if you want to keep the rate of filtration high, you have to keep on increasing the pumping to sustain the cross flow. So, sometimes we may go into microfiltration followed by, conventional filtration or even centrifugation to separate the solids completely.

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Now, let us go to ultra filtration. Now, ultra filtration pressures are slightly higher. So, in microfiltration we are talking about 1 to 2 bar then goes to ultra filtration where the pressures are around 2 to 10 bar. So, separation is based on the molecular sizes. So, it is very useful in separation of high molecular weight products, polymers proteins, colloidal materials from low molecular weight solutes. So, I want to separate out proteins and I have some low molecular weight solutes.

It can be used for concentrating and clarifying fruit juices; that means, we can concentrate fruit juices, as I said we cannot use distillation here, we can even clarify fruit juices because when you prepare fruit juices you may have suspended matter which will spoil appearance of the fruit juice, we can use it for recovery of whey proteins when you are manufacturing in cheese.

We can use it for concentrating cell free fermentation broths, containing monoclonal antibodies so; that means, I want to remove whatever cells, that are still left behind during my conventional filtration or during my microfiltration then I can go to ultra filtration. So, this comes as a second step in my filtration process.

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So, the material of construction, we can have polysulphones or other polymers it can have finely made microporous and the pore size could be asymmetric also. So, this pore size is much smaller than microfiltration. Pore area per unit surface is also less. So, the flux will be much lesser and compare to MF.

So, the liquid flows through the membrane because of viscous flow and you are applying moderate pressure, the osmotic pressure is negligible in microfiltration, when compare to RO or when compare to nanofiltration, because you have high molecular weight of the solute. So, the microfiltration operates more like a viscous flow.

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The flux in ultra filtration is reduced due to concentration polarization, because slowly, slowly the solids are going to get accumulated, the solute is going to get accumulated in the upstream, at the surface of the membrane. So, the flux starts decreasing, we cannot keep on increase in the pressure drop because again that depends upon your membrane characteristics.

So, here also you are going to have incompressible gel layer formed because of the concentration polarization and if you remember, the concentration, polarization, equation is J is equal to k logarithm g by C b now, k can be called a constant or it is a made up of a diffusion coefficient, it is made up of boundary layer and so on actually.

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So, J is independent of pressure drop because J depends only on the diffusion now, we have only diffusion coefficients coming into picture, the boundary layer coming into picture, the concentration in the bulk and the concentration of the gel or concentration at the polarization layer comes into picture actually. Now, J is independent of pressure drop now, rate of loss of solute will be equal to solute flow through the permeate. So, one we have is d V C by d t is equal to J into, A into, C p or d V C by d t is equal to JAC into 1 minus R.

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Where V is your retentate volume, C and C p are the concentration of the solute in the retentate and the permeate A is the area of the membrane R is the retention coefficient.

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So, R is your retention coefficient, A is your area, C p is the concentration of In the permeate side c is the concentration In the solute in the retentate.

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If the retention coefficient for the solute R equal to 1 then VC will be a constant.

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VC will be constant here. So, because 1 minus R will become 0.

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If R is less than 1 then we can take out c outside and then have d V by d t or we can take V outside then the equate d C by d t this is equal to JAC 1 minus R this is for R less than 1 that is the retention coefficient. Now, d V by d t can be replaced by J into area J is your flux A is your area. So, what we have is a equation here, this equation tells you how the changes in the filtration rate or how the changes in the concentration, affect your flux on this side that is, what this particular equation tells you.

And this equation is valid if R is less than 1, if R is equal to 1 then we will be neglecting that part. So, you see in ultra filtration, the concentration polarization plays a very important role whereas, in a microfiltration it is more like a normal filtration process where the compressibility of the cake plays a very important role. So, there we are not talking about any concentration polarization, there buildup of cake it is like a normal filtration process using a cloth or a metal sheet or something like that.

But, here the concentration polarization buildup of the solute, which forms a gel which will slowdown your rate of filtration as the gel concentration keeps increasing the rate of filtration also keeps decreasing. So, as the gel layer increases again the rate of filtration also keeps going down. So, at some point we need to re either remove, this gel layer by doing a back flushing and beyond some point we may have to replace the filter medium itself; that means, we need to replace the membrane material itself, to bring your rate of filtration to its desired or normal value.

So, these are the two main things that happens, when you are talking about your microfiltration and the ultra filtration.

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So, we are going to use quite a lot of solute.

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Where V - retentate volume, C and Cp are the concentration of solute in the retentate and permeate respectively, A – Area of the membrane R – retention coefficient. If the retention coefficient for a solute R = 1, then VC will be a constant as per the above equation . However if R < 1 then $-C_{s}\frac{dV}{dt} - V\frac{dC}{dt} = JAC(1-R)$ Replacing (-dV/dt) by JA and V by Vi –Ja_t and integrating from t = 0, C = C₁ to t = t and C = C₁ gives

During this ultra filtration process because of the concentration polarization and solute does not diffusion through the gel layer or the concentration layer. So, we will continue on this further in the next class.