Membrane Technology

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Lectute-18
Nanofiltration Basics, Transport Mechanism, Fouling Model and Applications

Good morning students, today is lecture 18th of module 6. In todays lecture will basically discuss about Nanofiltration.

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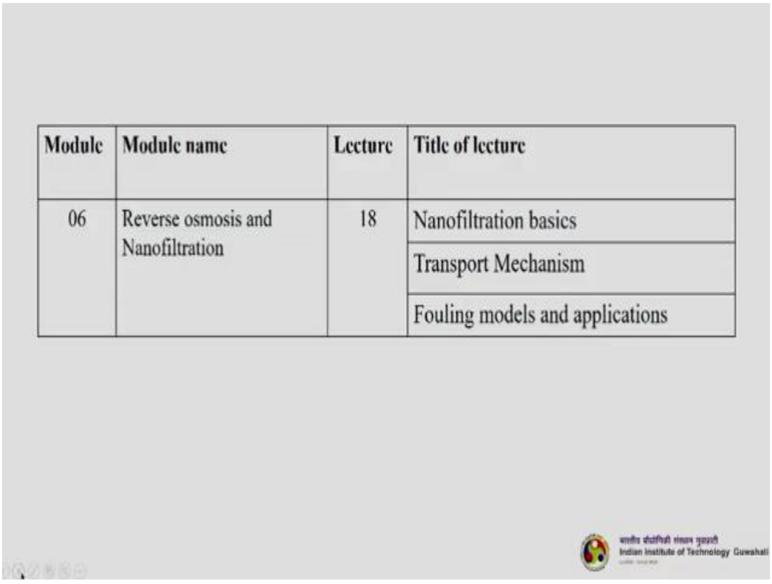

Module	Module name	Lecture	Title of lecture
06	Reverse osmosis and Nanofiltration	18	Nanofiltration basics
			Transport Mechanism
			Fouling models and applications

We will try to understand what is nanofiltration and I will tell you how nanofiltration and reverse osmosis overlaps each other. And what is the difference between them, we will try to see also learn also what is the transport mechanism of nanofiltration and systems and do various fouling models and the various applications of nanofiltration.

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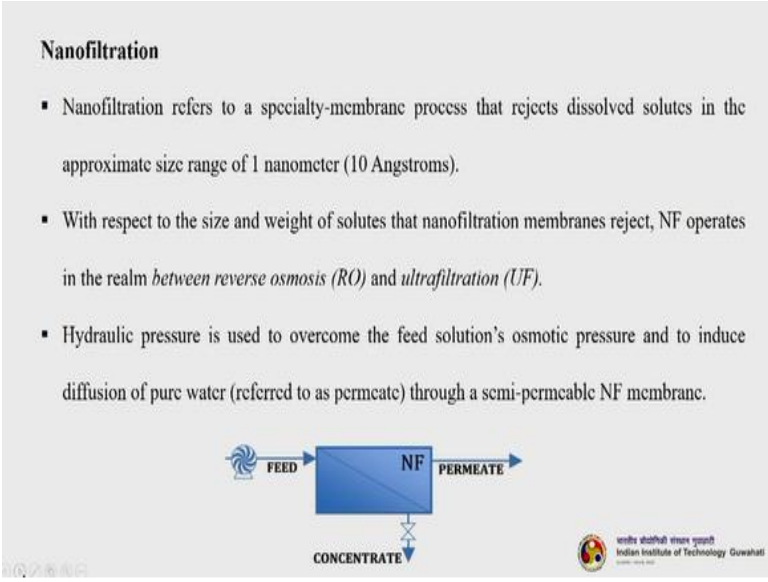

So as you know, nanofiltration refers to a specialty membrane process that rejects dissolved solutes in the approximate size range of 1 nanometre of 10 Angstroms. So very small size solutes are being rejected. With respect to the size and weight of solutes that nanofiltration membranes reject nanofiltration operates in the realm between reverse osmosis and ultrafiltration. So actually, based on the range of the solute it rejects the membranes have been classified.

So nanofiltration can lies something somewhere between the cutoff of reverse osmosis, and ultrafiltration. Hydraulic pressure is used to overcome the feed solution osmotic pressure, and to induce diffusion of pure water, which we also called as permeate through a semi permeable membrane.

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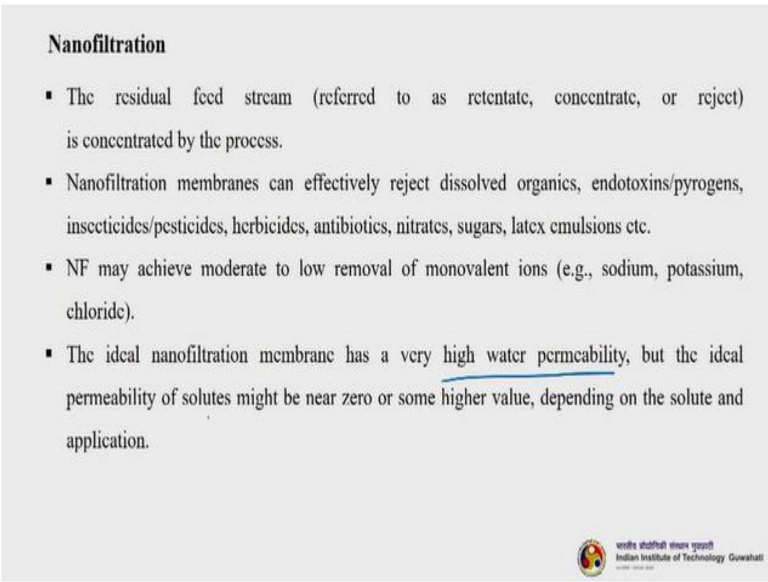

There residual feed stream reffered to as retentate, concentrate or reject is concentrated by the process. Nanofiltration membrane can effectively reject dissolved organics, endotoxins and pyrogens, insecticides and pesticides, herbicides, antibiotics, nitrates, sugars, latex emulsions etc. and nanofiltration may achieve moderate to low removal of monovalent ions. For example, sodium, potassium, chloride etc.

And ideal nanofiltration membrane has very high water permeability, right? But the ideal permeability of solutes might be near 0 or some higher value, depending on the solute and application. So, an ideal nanofiltration will pass as much as water, permeate as much as water, however, returning all source of solutes and ions.

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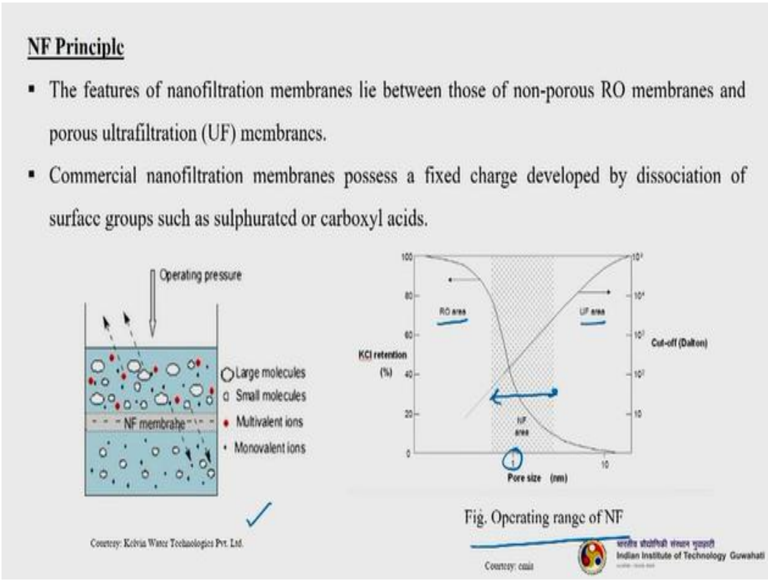

The features of nanofiltration membranes lie between those of non-porous RO membrane and porous ultrafiltration membranes; this is what we just discussed. Commercial nanofiltration membranes possess a fixed charge developed by dissociation of surface groups such as sulphurated or carboxylic acids. So you can see this particular figure here that how nanofiltration is rejecting large molecules, small molecules and multivalent ions.

However the monovalent ions, because of very small size are passing through the membrane along with water. Here this particular figure will tell you the operating range of the nanofiltration and you can see the pore size is 1 nanometre here, okay? Nanofiltration is range between here, RO here, this is RO, and this is ultrafiltration range. So, RO less than 1 nanometre mostly here, and UF greater than 1 nanometre almost into the range of 10 nanometre and higher size.

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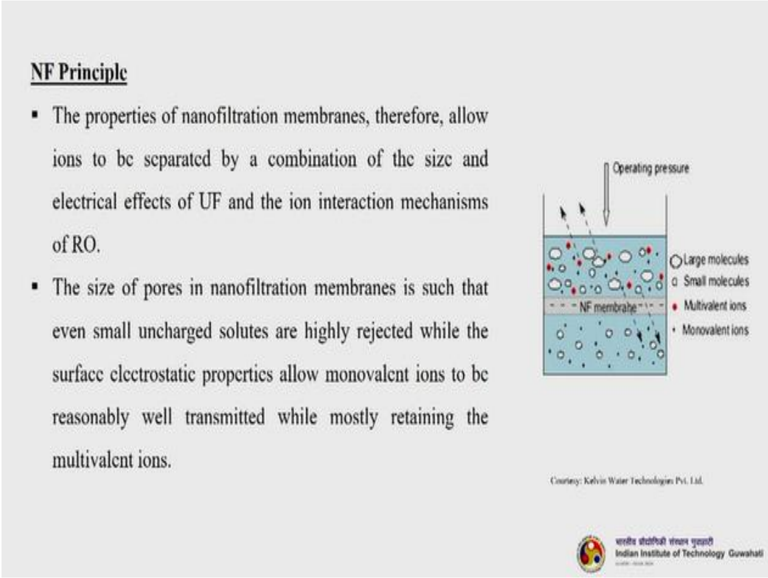

The properties of nanofiltration membranes, therefore, allow ions to be separated by a combination of the size and electrical effects of UF and the ion interaction mechanisms of RO. So that means note that, the NF actually works in the combined principle of UF and reverse osmosis, UF basically sizes represent membrane and process, as well as charged separation also affects.

However, in RO the ionic interaction plays a major role. So in NF both the all these things are playing in a while rejecting a solute or permeating the water, the size of pores in nanofiltration membranes is such that, even small uncharged solutes and highly rejected while the surface electrostatic properties allow monovalent ions to be reasonably well transmitted while mostly retaining the multivalent ions.

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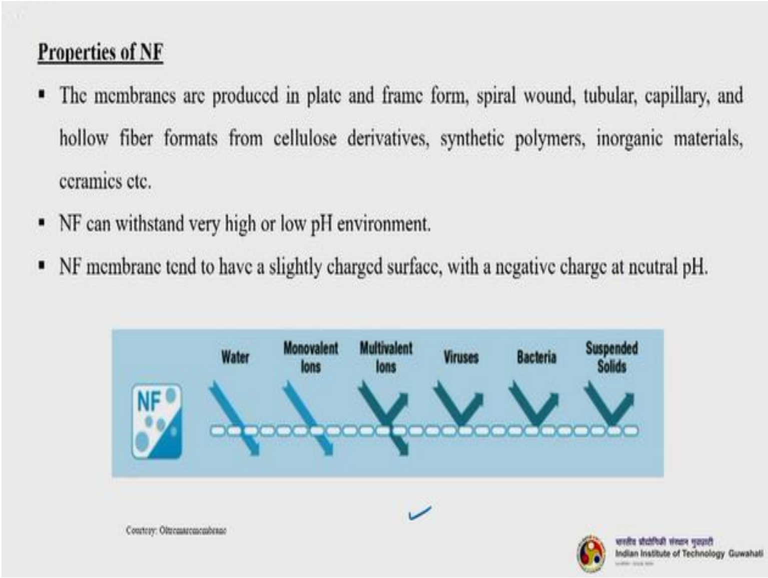

Now, look at that, further properties and look at this particular schematic here. You can see this water and monovalent ions are mostly being transmitted or pass to the permeate side, whereas multivalent ions, most of the multivalent ions are developed as viruses, bacteria, suspended solids, all are we getting rejected. Some multivalent ions will occurs pass through the membrane because of the various non ideal semi permeable membranes that is actually existed.

So, NF membranes can be produced in plate and frame form, spiral wound, tubular, capillary and hollow fiber formats, from various membrane materials mostly cellulose derivatives, maybe there are some synthetic polymers, and then inorganic materials also, ceramics also available. Now, NF can withstand very high or low pH environment. NF membrane tends to have a slightly charged surface with a negative charge at a neutral pH.

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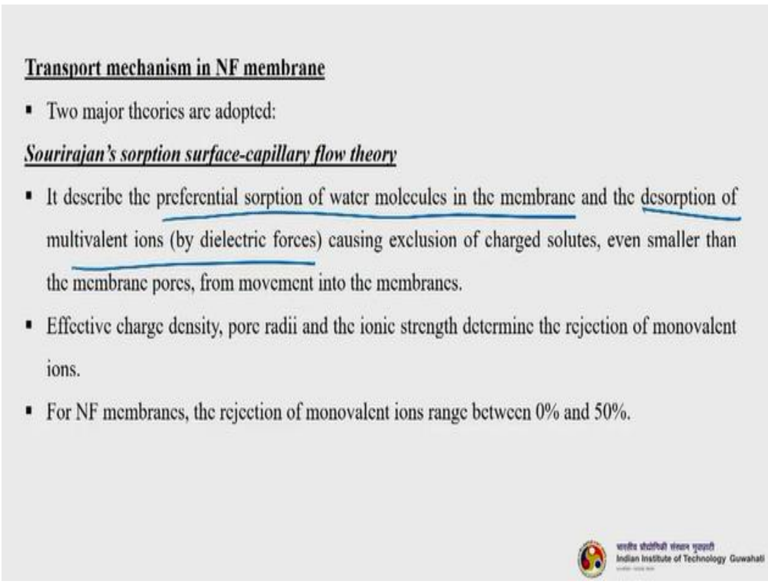

Two types of transport theories or models are basically adapted to describe the nanofiltration transport. So first one is the Sourirajan's sorption surface capillary flow theory and the second one is the usual solution diffusion model which we have discussed in detail in our previous classes. So, in Sourirajan's sorption surface Capillary Flow theory, so actually it describes the preferential sorption of water molecules in the membrane.

And then the desorption of multivalent ions by dielectric forces, causing explosion of charged solutes even smaller than the membrane pores, from movement into the membranes. So that means the membrane and the water molecules are getting served inside the membranes. Okay, then they are passing through the permeate cell, and that desorption of multivalent ions are happening due to the dielectric process because we just discussed that the membrane NF membranes are slightly negative in charge.

So, smaller than the pore size of the membranes, ions are also getting rejected. So the effective charge density, pore radii and ionic strength determine the rejection of monovalent ions. For nanofiltration membranes the rejection of monovalent ions ranges between 0% to 50%.

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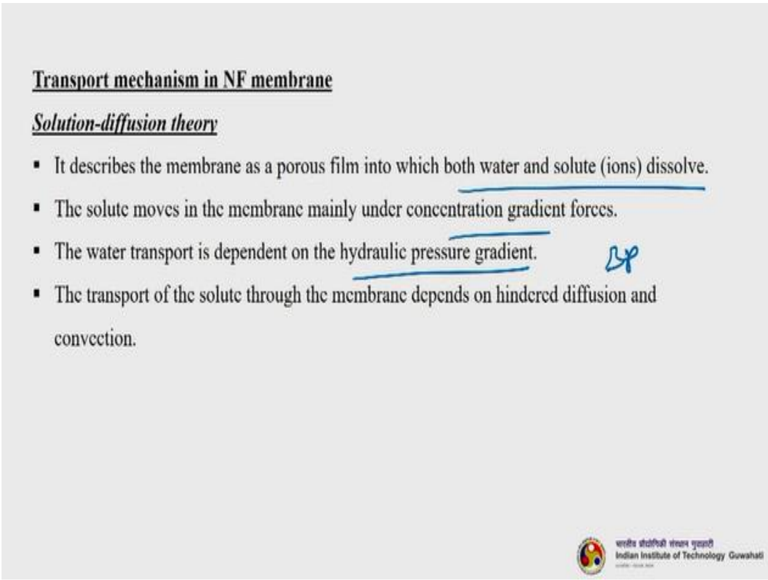

So the solution diffusion this way discussed, as I told you in detail earlier it is the same for the RO we have discussed, so it describes the membrane as a porous film into which both water and solute ions dissolve. Whatever is getting water has to be served inside the membrane material, and then only it will get to into the permeate side. Similarly, the solute ions which are supposed to be transmitted through the membrane must dissolve itself in the membrane material.

Then sorption will take place, the solute moves in the membrane mainly under the concentration gradient forces. The water transport is dependent on the hydraulic pressure gradient, so that means more you are giving supplying the delta P, so more will be the water flow and the transport of the solute through the membrane depends on the hindered diffusion and convection.

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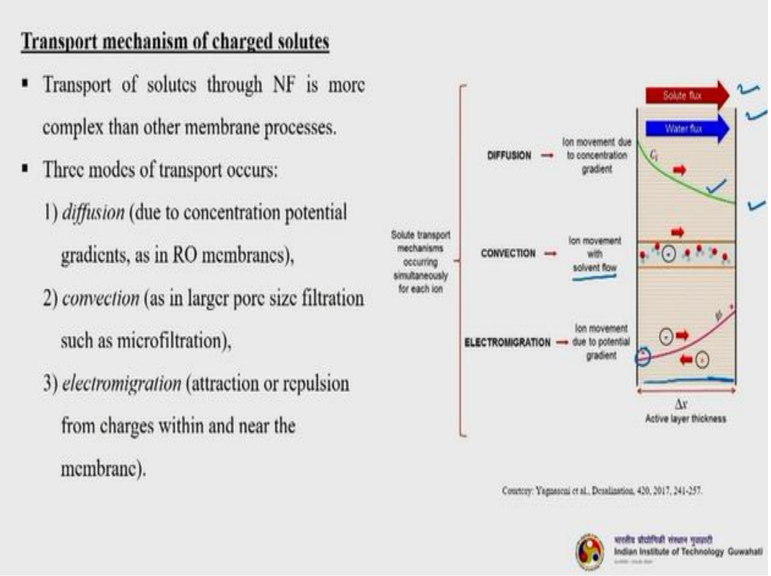

So let us understand the transport mechanism of the charged salutes in NF, transport of solutions through NF is more complex than any other membrane processes, actually 3 different modes of transport occurs; the first is diffusion, which is due to the concentration potential gradient in the reverse osmosis membranes, then convection in the larger pore size filtration such as microfiltration or ultrafiltration, then electromagnetism, attraction or repulsion from charges within and near the membrane.

So you can see this particular image which was actually proposed or given by one of the paper in desalination given by Yagnaseni et.al. So this is the solute transport mechanisms occurring simultaneously for each ion. Now, the mechanism also depends upon the feed water, and its composition. This is your Of course this is the membrane, right? So activity or thickness given by delta x and the water flux and solid flux both in this direction.

So you can see diffusion is a ion movement due to concentration gradient, okay? So you can see this is given by this particular line. So you can see there is a concentration grant in the downstream side. So that is why movement of ions will happen to the diffusion. Then conviction; so iron movement with solvent flow, so along with solvent that means, along with the water some ions are flowing through. So this indicates that the membrane are having some pores, so they are pores, some pores are existing, okay?

Otherwise, if there are no pores, absolutely no pores membrane then convention will not happen basically. So then there is electromigration, so that means ion movement due to potential gradient. So as you know that ion membrane is slightly negatively charged, you can see this, right, and then up stream side we are maintaining some positive charged, so ion movement takes place by the flow of cations and anions in both ways and ion movement will take place both ways.

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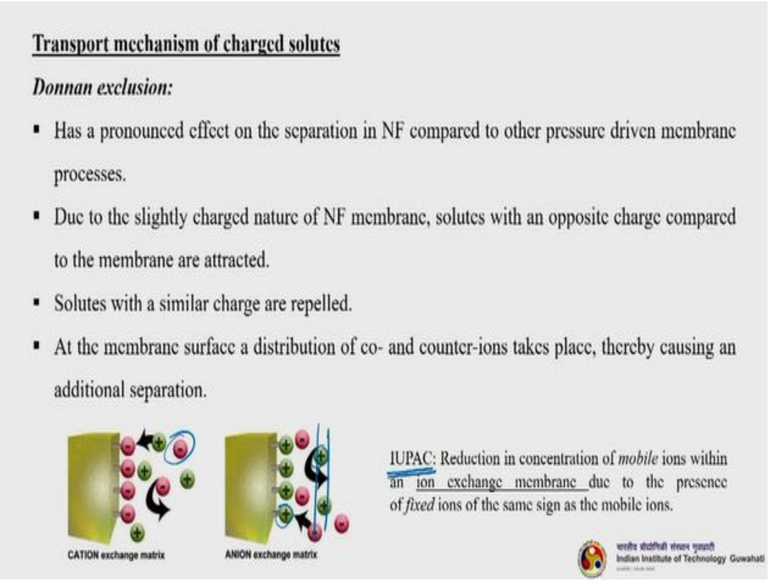

So, transport mechanism of charged solutes can be explained by 3 things actually. One is, Donnan exclusion, the next is actually a dielectric exclusion and then there is also something called the steric exclusive. So we will learn what is all this things one by one. So Donnan exclusion, actually what is Donnan exclusion, if you see the IUPAC actually definition. It says reduction in concentration of mobile ions within an ion exchange membrane due to the presence of fixed ions of the same sign as the mobile ions.

So that means you see the cation ion matrices, which are having this negatively charged ions already onto them, so, it will repeal this same charge groups. Similarly, an ion exchange membrane which are having this fixed positive charge, for all the positive changes their way attracting the opposite charge. So this is, and then after some time some equilibrium will be observed here. So that is actually called on an equilibrium.

So, Donnan exclusion has a pronounced effect on the separation in NF compared to other pressure driven membrane processes because we are mostly dealing with the ions, so each ions are having some charges. Due to the slightly charged nature of NF membrane, salutes with an opposite charge compared to the membrane are attracted. Solutes with a similar charge are repelled. At the membrane surface, a distribution of co and counter ions takes place, thereby causing an additional separation.

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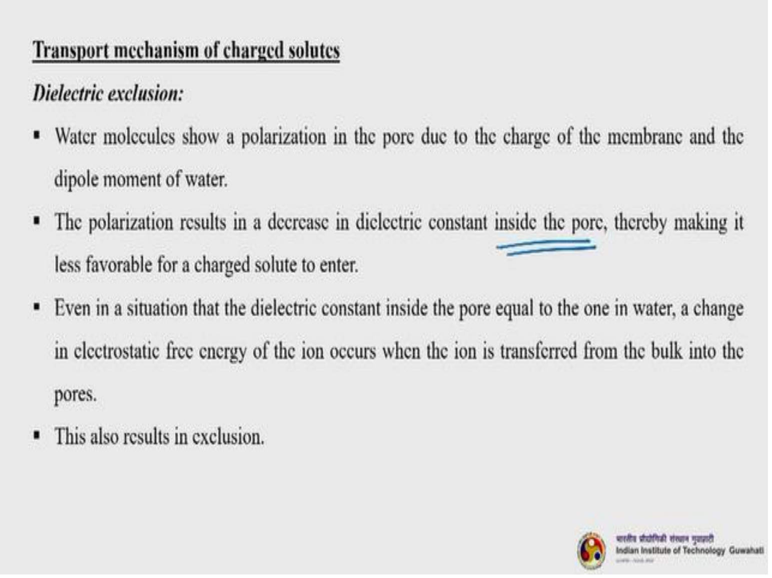

So the next one is dialectic exclusion; now water molecules show a polarization in the pore due to the charge of the membrane and the dipole moment of the water. The polarization results in a decrease in dielectric constant inside the pore, thereby making it less favorable for a charged salute to enter. That means, when the water is getting polarized inside the pores. It is hindering the diffusion of solutes inside that pore.

So this is what is actually known as dielectric exclusion. So even in a situation that the dielectric constant inside the pore equal to the one in water, a changed in electrostatic free energy, of ion occurs when the ion is transferred from the bulk into the pores. So, this also resulted in exclusion.

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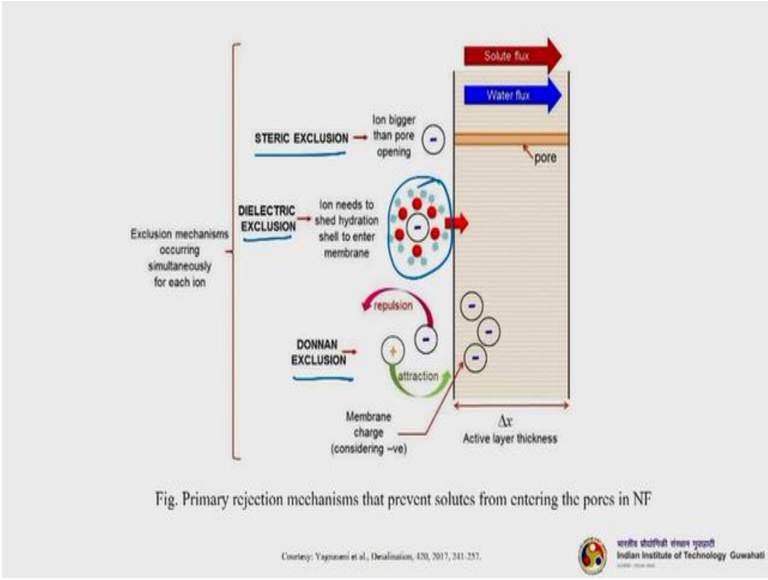

Let us see this particular figure again given by a Yagnaseni et.al, the desalination of this particular, you can refer to this nice publication actually, this materialistic so you can see this exclusion mechanisms occurring simultaneously for each ion, steric exclusion, this is nothing but side exclusion, than your dielectric exclusion, then Donnan exclusion. So you can see this at in steric exclusion, ion bigger than the pore opening, Okay?

They are trying to, they will be actually rejected on the surface of the membranes exclusion means we are talking about rejection how rejection is happening rejection of solutes from the membrane surface is happening then the dielectric exclusion something like this will happening. So, ion needs to shed hydration cell to enter the membrane. So it is difficult, because the membrane is already charged, some charge, Okay?

Then there are counter ions will be there, so they will try to form some groups on something like this is some, some structure something like this. So thereby there is rejection of the oppositely charge which is similar charged particles, ions will happen. So then we have Donnan exclusion, so here the repulsion expulsion happening due to the positive or negatively charged ions. So membrane charge considering it is negative.

So, we will see this, how the repulsion is happening, Okay? So, this particular figure tells us the rejection mechanism of the charge solutes on the nanofiltration membrane.

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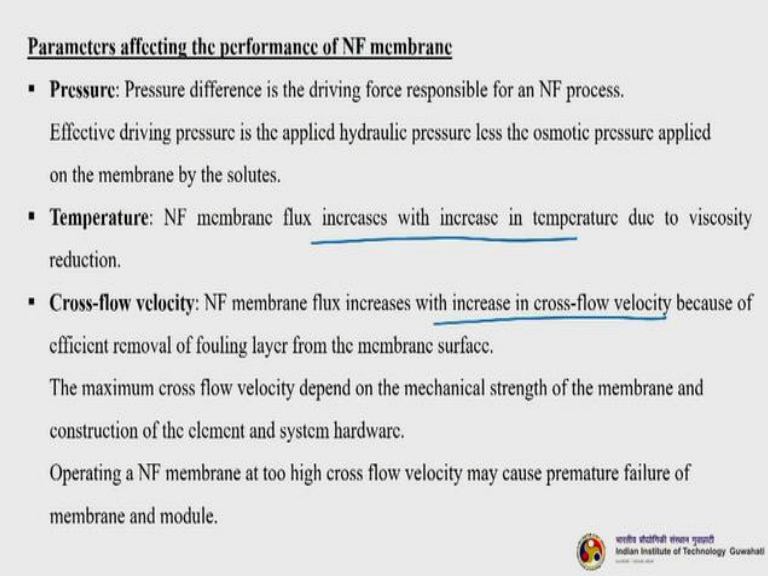

So let us now understand the different parameters that affect the performance of an nanofiltration membrane. So, there are various parameters we will see one by one. First one and foremost one is of course the pressure; pressure difference is the driving forces responsible for an nanofiltration membrane. So effective driving pressure is the applied hydraulic pressure, less the osmotic pressure, there is applied on the membrane and by the solutes, Okay?

Temperatures on nanofiltration membrane flux will increase with increasing temperature, due to the reason is that when the temperature increases the viscosity is reduced. That is where the flux getting's enhanced. Then cross flow velocity; so nanofiltration membrane flux increases also go along with that increasing the cross flow velocity. Why? Because if there is a higher cross flow velocity.

Then, here what it will do is basically the cell will wash away the concentrated concentration polarization layer, or we can say that the deposition whatever is happening on the surface of the membranes will be washed away due to a higher flow rate. So, thereby reducing the concentration polarization actually is falling. So the maximum cross flow velocity depend on the mechanical strength of the membrane and construction of the element and system hardware.

Operating a NF membrane at too high cross flow velocity may cause premature failure of the membrane and module. So, it is true that you cannot operate a NF system, beyond a certain pressure. Otherwise your system will failure and membrane will get rupture.

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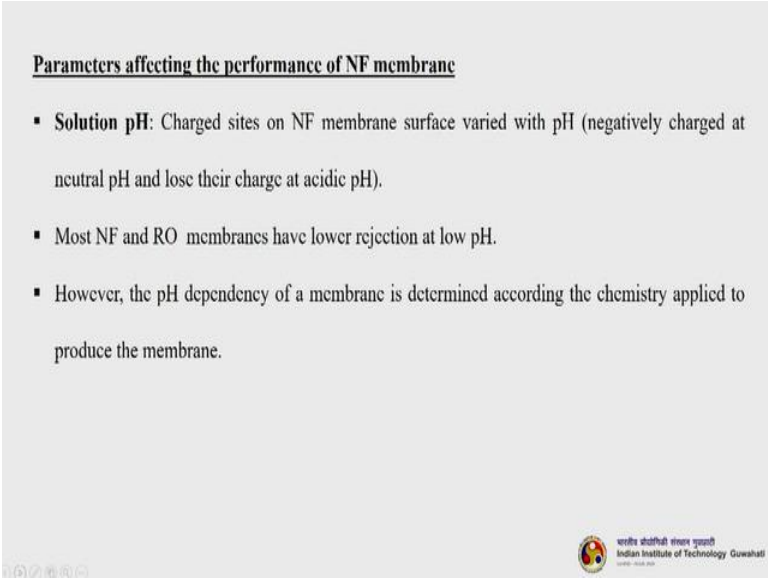

So the next other parameter says solution pH, so you know solution pH is the one of the most important parameter, whenever you talked about any liquid systems. Okay, liquid phase systems, whether you were doing some separation carrying out some reaction, whatever. So, charged sites on the NF membrane surface varied with pH. So negatively charged at a neutral pH and lose their charger acidic pH.

So most NF and RO membranes have lower rejection at low pH. Because of the surfaces are already charged and mostly it is negatively charged at neutral pH. However the pH dependence upon membrane is determined, according to the chemistry applied to produce the membrane.

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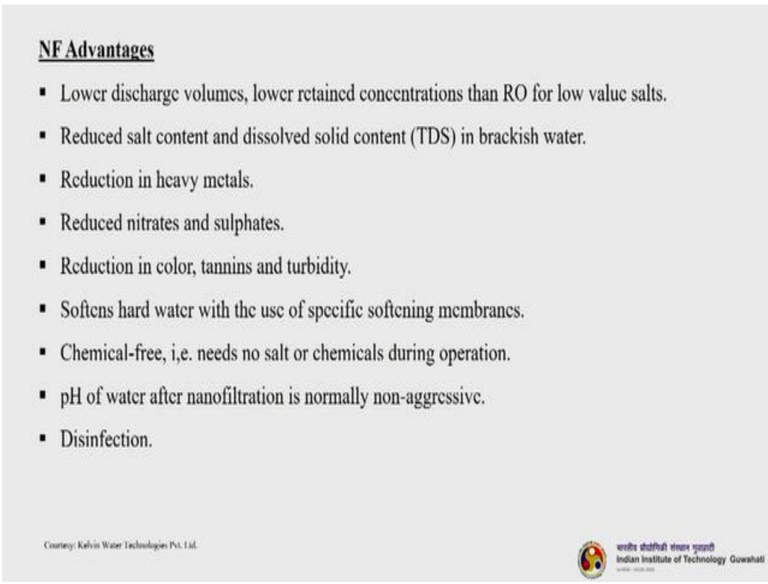

So let us understand the nanofiltration advantages. So, it has lower discharge volumes, lower retained concentrations than RO for low value salts. Reduced salt content and dissolved solid content in brackish water. Reduction in heavy metals, reduced to nitrates and sulphates, reduction in color, tannins and turbidity, Softens hard water with the use of specific softening membranes. Chemical free, that is needs no salt or chemicals during the operation.

And pH of water after nanofiltration is normally non aggressive and disinfection. So, these are the thing that is being done by the nanofiltration membrane.

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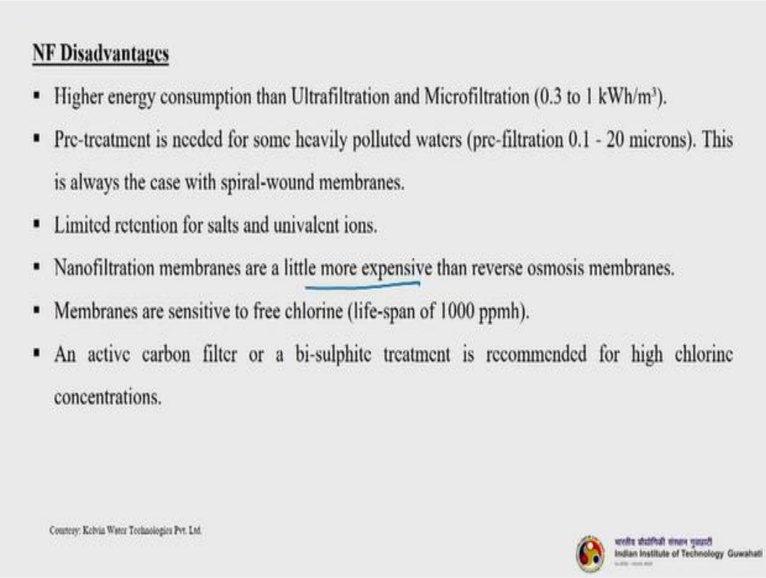

So, it has certain disadvantages also. So higher energy consumption than ultrafiltration and microfiltration and so almost 0.3 to 1 kilowatt hour per meter cube. So, another important thing is that pre-treatment is required for some heavily polluted water, so pre-filtration 0.1 to 2 microns. The all these things needs to be removed. Otherwise, your membrane will be blocked, and it will not give the targeted performance.

So this is always the case with spiral wound membranes, see the spiral wound membranes typically frames as it leaves you, we have understood how spiral wound actually work in our membranes module discussion as well as in RO also. So you know the how it is being fabricated. So the space in between is to less. So they are more pore to fouling. So, it is important that there is a statement before nanofiltration, okay?

For heavily polluted it is not that every water streams are paid water has to be pre-treated. So limited retention for salts and univalent ions, nanofiltration membranes are little more expensive than reverse osmosis membranes. So membranes are sensitive to free chlorine, so most of the time chlorine is present in water and water streams. So they are not very good chlorine resistance membranes, so life span of 1000 ppmh, Okay?

So an active carbon filter or a bi-sulphite treatment is recommended for high chlorine concentrations.

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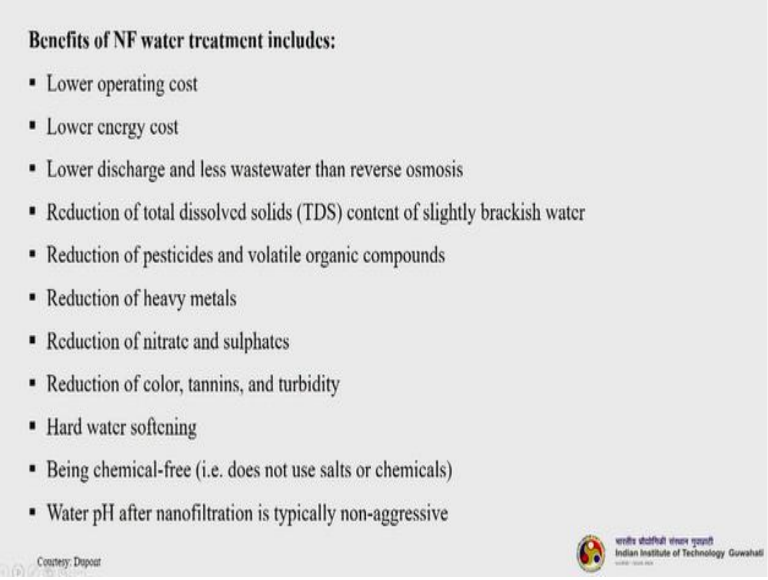

Let us understand the benefits of the NF water treatment; so most of the times, NF is actually used to produce potable water. So in that case, what are the advantages; so the operating cost actually is very less, energy costs also less, lower discharger and less wastewater than reverse osmosis and the principal produces. Then reduction of total dissolved solids content of slightly brackish water.

Reduction of pesticides and volatile organic compounds, reduction of heavy metals, reduction of nitrates and sulphates, reduction of color, tannins and turbidity, hard water softening. Being chemical free say does not use any salts or chemicals. Water pH after nanofiltration is typically non-aggressive.

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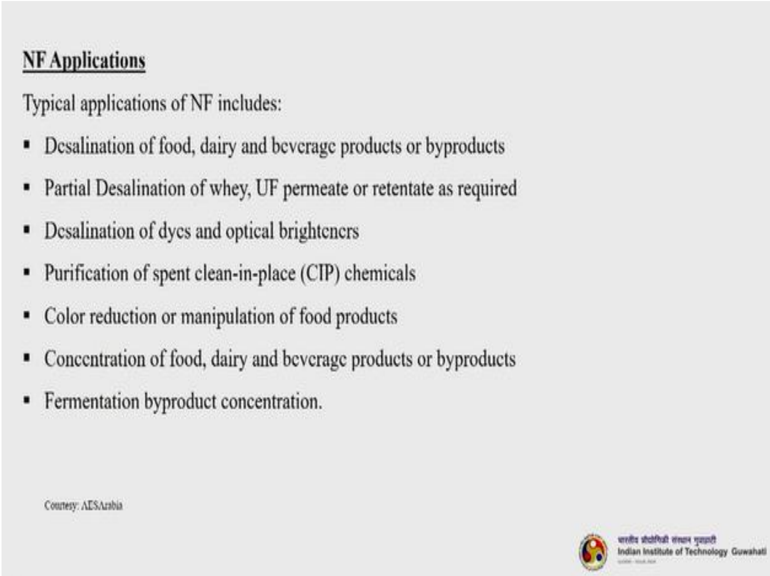

So NF applications includes; the desalination of food, dairy and beverage products or by-products. Partial desalination of whey, UF permeate or retentate as required. Desalination of dyes and optical brighteners. Purification of spent clean in place chemicals, CIP chemicals. Color reduction or manipulation of food products. Concentration of food, dairy and beverage products or by-products. Fermentation byproduct concentration.

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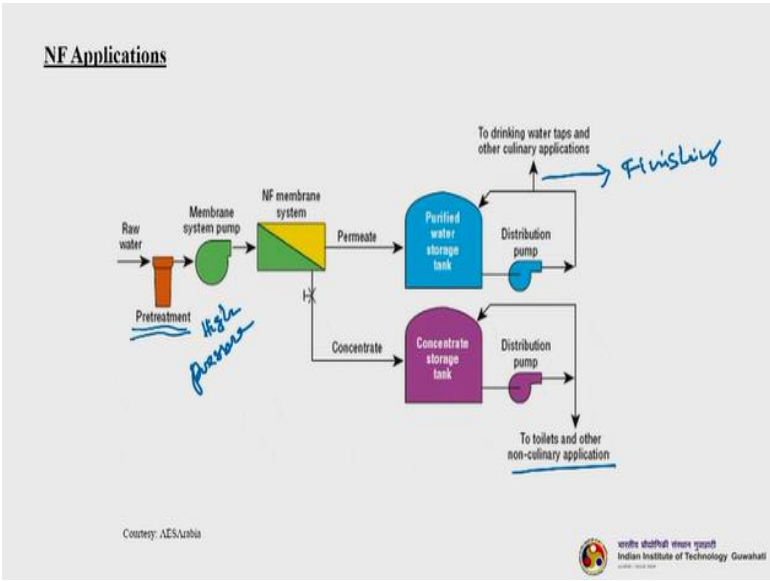

Let us see one; this is one application, in which the nanofiltration membrane is used to produce clean water, even for drinking water taps as well as other culinary applications. So you can see the schematic here, so raw water is coming as I told you that, one of the disadvantages, in nanofiltration is that it needs a pre-treatment and not always, but most of the times. Depending upon what is your feed water composition and what it contents basically.

So then it goes to trio pump, basically this is a high pressure membrane system pump is a high pressure pump, okay? So this high pressure pump will pump the raw water or filter to the nanofiltration system. So you get permeate and a concentrated. So the permeate is goes to the purified water storage tank, Okay? Then it can be taken for the culinary or drinking water taps, or there is purified water, or it may be recycled by partly to maintain the volume.

see many times, here also, this one needs another finishing step, this finishing step is basically required because most of the ions are divide. When we are doing the nanofiltration, so it is actually when we are talking about the potable water system or potable water applications. So you need to sometimes re-mineralization, re-mineralize the NF water. So the concentrate which is coming here and getting stored here, so, this concentrate is also can be used to toilets and other non-culinary application.

You can use it for watering your plants in the garden and all these things. So you have been used in the toilets many of the big hotels star hotels are now are doing are adopted this technology, and you will see this in the wash room many times it is written that, especially in your commodes you can see the color of the water is slightly, slightly greyish or a little yellowish it is written within that, because this is treated water. So, there is some color

So you can remove the color also completely but it will be unnecessarily above the process what of course so it is not required. So, whatever you are using for your bathing or your drinking purposes or washing, so you will get them, you will obviously being supplied with the good water.

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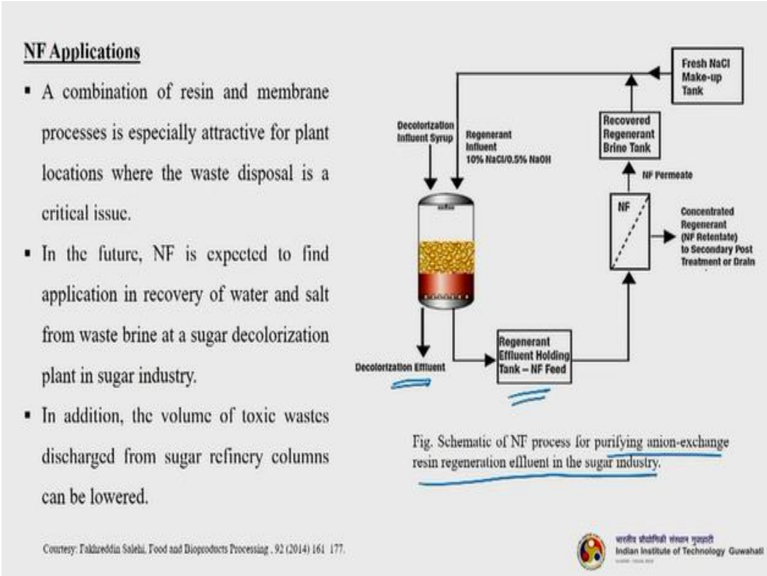

So another NFL application is the NF process for purifying anion exchange resin regeneration effluent in the sugar industries. So, here what is happening actually a combination of a resin and membrane processes is especially attractive for plant locations, where the waste disposal is a critical issue. Now most of the industries that do not have land for waste disposal, and the rest of them to rules, of course waste disposal also being imposed.

So it is imperative that they need to treat it. So in the future, NF is expected to find applications in the recovery of water and salt from waste brine at a sugar decolorization plant in sugar industry. So these are also getting adapted now a day. So in addition, the volume of toxic wastes discharged from sugar refinery columns can be lowered. So you can see how it is happening, actually.

So, this regenerate effluent that is the first is coming and you are adding some decolorizations. So, the decolorizations effluent is being taken here, and it regenerated effluent, Okay? Which is being stored here. So this is basically NF feed, it goes to the nanofiltration system, where you are getting the concentrate the region, which is the NF retentate to secondary post treatment of drain, or you can just use it again, as I told you, for watering garden and all this purposes, non-culinary purposes, and the NF permeate. Okay?

So this is nothing but recovered regenerate brine tank goes and stored there, so this will be recycled brine.

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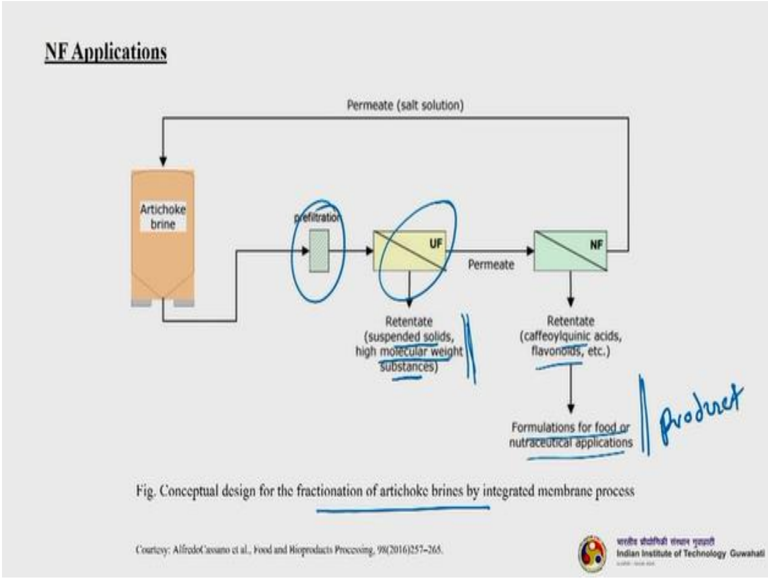

So there is this is another application. This is a conceptual design for the fractionation of artichoke brines by integrated membrane process. Now here, this is a hybrid system you can say, okay, usually we say a hybrid system is something where two different unit operations are plugged together. Okay? But here two different, two different membrane systems are plugged together.

So you can say integrator membrane process, so you can see here, there is an ultrafiltration membrane, there is nanofiltration membrane, Okay? Why it is being used so let us try to understand so artichoke brine is stored here. See our artichoke brine is being feed to the ultrfiltration membrane. So before being to the ultrfiltration membranes some, some sort of prefiltration happens to remove the floating solids, suspended solids have certain, certain other larger molecular compounds.

So, that the UF membrane will not, UF membrane being porous it should not get clogged. So this filter artichoke brine then goes to the UF membrane, where we are getting the retentate, so the retentate is getting artichoke brine, suspended solids, higher molecular weight substances, okay? But now we will try to understand that why we are using UF here. If you do not use the UF here, directly feeding the artichoke brine after this brief filter, okay?

To hear, them all these whatever the UF is getting rejected will be rejected here but the membrane performance will decrease drastically, Okay? So that is why there is a need to actually refilter, as well as there is a need to place a UF, so that the UF will remove most of the suspended solids and the high molecular weight components. So the permeate divide all these things, Okay? and having only smaller molecular weight compounds and ions is being feed to the NF.

So the NF retentate is basically like caffeoylquinic acids, flavonoids etc., and this goes for the formalization for food or nutraceutical application. So this is actually our product of interest. Okay? And, whatever the permeate is, there it is getting recycled here. Oka? So it is the salt solution, mostly right so again going artichoke filter tank.

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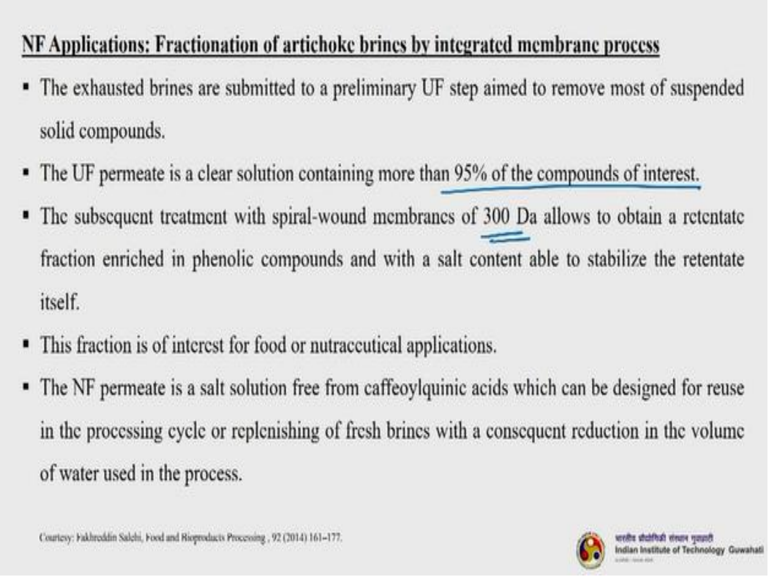

So, the artichoke brines are submitted to a preliminary ultrafiltration step, aimed to remove most of the suspended solid compounds. This is what I already told you, so the ultrafiltration permeate is a clear solution containing more than 95% of the compounds of interest. So, it takes out all the larger molecular weight components as well as your TDs, most of the suspended solids.

So, components which are smaller molecular weight components this caffeoylquinic acids, flavonoids etc. So they will be fed to the nanofiltration system. So the subsequent treatment with spiral wound membranes of 300 Da allows to obtain a retentate fraction enriched in phenolic compounds, and with a solid content able stabilize the retentate itself. So, this fraction of interest for food nutraccutical applications.

So the NF permeate is a salt solution free from caffeoylquinic acid, which can be designed for reuse in the processing cycle or replenishing of fresh brines with a consequent reduction of the volume of water used in the process.

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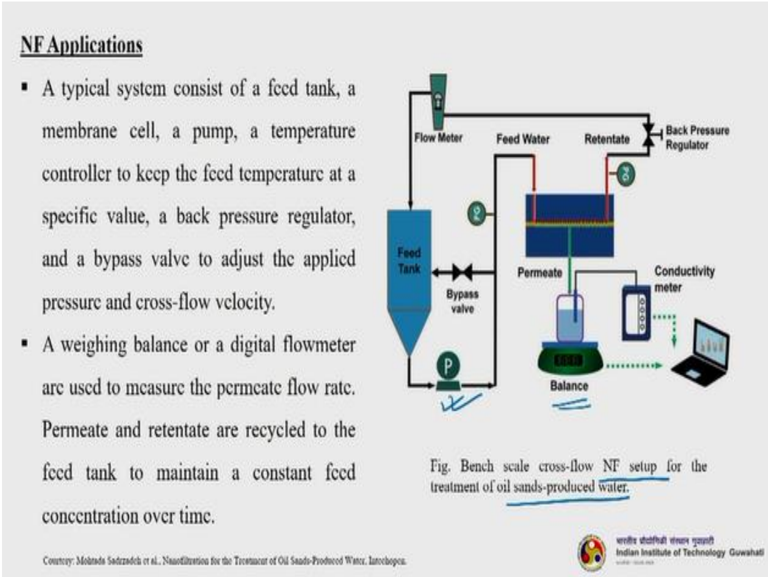

So this is another classic example of the scale cross-flow NF setup, Okay? For the treatment of oil sands produced water. So you can see this, there is a tank, Okay? So then it is high pressure pump is here, so it is pumping the feed water to the occultism number, where they are getting permeate here. Okay. And then the retentate is again being feed tank or it can be taken out also, okay?

A typical system consists of a feed tank, a membrane cell, a pump, a temperature controller to keep the feed temperature very specific value, a back pressure regulator and a bypass valve to adjust the applied pressure and cross flow velocity. So weighing balances here you can see this, or a digital flow meter used to measure the permeate flow rate. Permeate and retentate are recycled to the feed tank to maintain a constant feed concentration over time.

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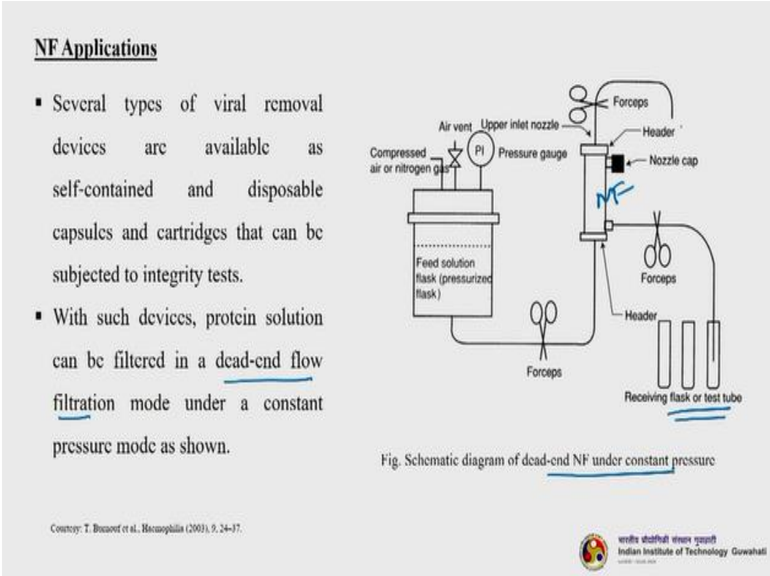

Another application, this is dead-end nanofiltration under constant pressure. You can see this is several types of viral removal devices are available as self contained and disposable capsules and cartridges that can be subjected to integrity tests. So with such devices, protein solution can be filtered in a dead-end flow filtration mode under constant pressure mode, you can see. So you can see this, this is NF system actually Okay?

So the proteins solutions are getting actually filter here. Okay, so you are getting the receiving flask or you have the test tube, whatever the permeate can be collected here.

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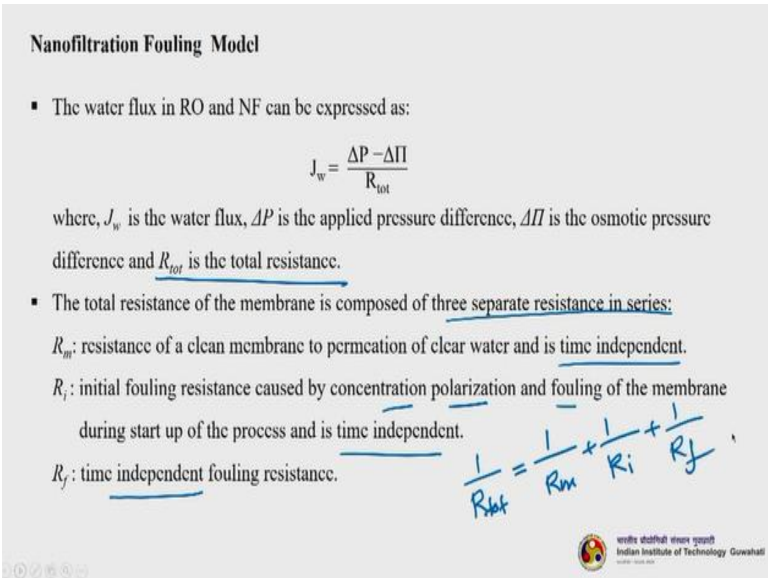

So let us now understand the nanofiltration fouling mechanisms and the models. So, the water flux in RO and NF can be expressed as; Jw equals to delta p minus delta pi by Rtot. So Jw is the water flux, delta p is the applied pressure difference, delta Pi is the osmotic pressure difference and Rtot is the total resistance, Okay?. Now the total resistance of the membrane is composed of three separate resistences in series, Okay?

So Rm, Ri and Rf , so Rm is the resistance of a clean membrane to permeation of clean water, and is time independent. Okay? So Ri is initial fouling resistance caused by concentration polarization, and fouling of the membrane, and, it is time independent, Okay? Rf is time independent fouling resistance. So you can write this, actually, we can write 1 over Rtot equals to 1 over Rm + 1 over Ri + 1 over Rf. this is how you right actually, this one the resistances.

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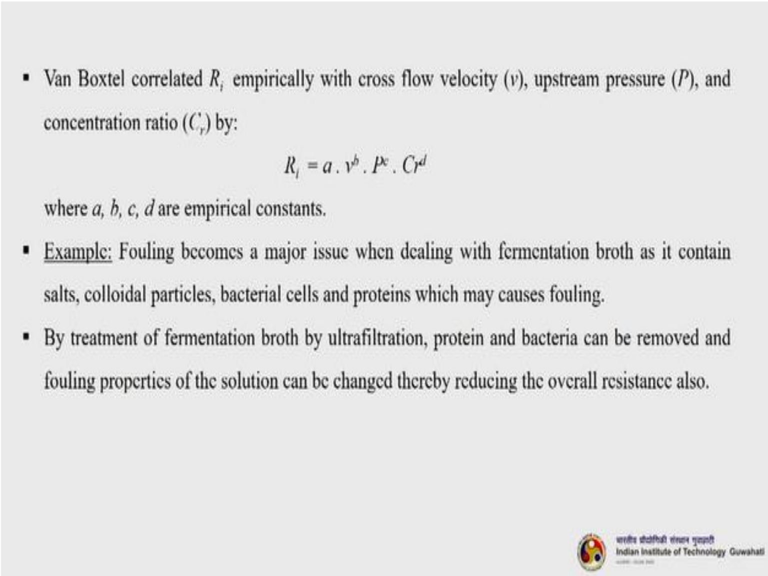

Van Boxtel correlated Ri empirically with a cross flow velocity, upstream pressure and concentration ratio and propose this particular equation. So, Ri equals to a. v to the power of b. P to the power of c and Cr to the power d. So Cr actually concentration this, so a,b,c d are empirical constants. For example why this is being necessary and we were talking about this actually fouling problems becomes very severe.

So for example, we are taking fermentation broth. So, the fouling becomes a major issue when we are dealing with fermentation broth as it contain salts, colloidal particles, bacterial cells and proteins, which may cause fouling, most of the marble apartments. So, by treatment of fermentation by ultrafiltration, some protein and bacteria can be removed and fouling properties of the solution can be changed thereby reducing the overall resistance also. Then again it can be sent to the nanofiltration system.

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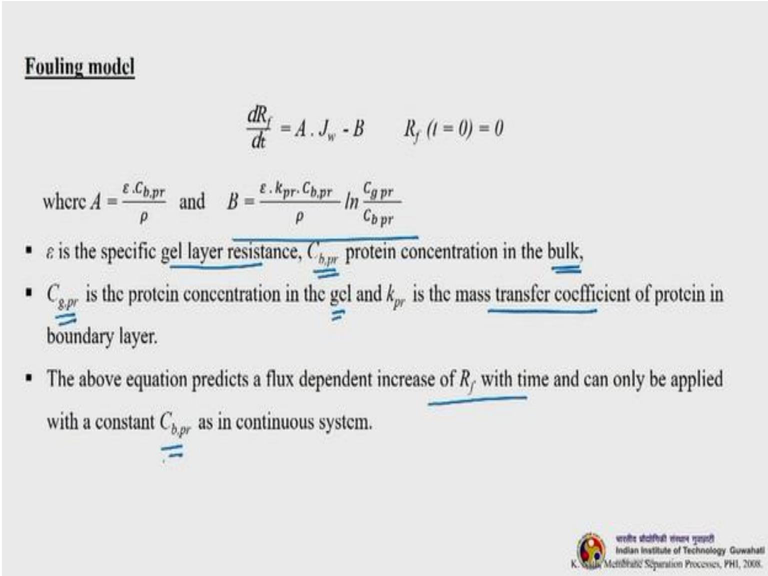

So, a fouling model can be expressed by this particular equation in the terms of Rf. So dRf dt equals to A into Jw -B. So, Rf at t equals to 0 equals to 0. That means Rf time 0 equals to 0. So where A is given by epsilon Cb.pr by rho and B equals, B is given by this particular equation. So, epsilon is the specific gel resistance. Cb.pr is the Protein Concentration in the bulk.

Cg.pr or is the protein concentration in the gel and kpr is the mass transfer coefficient of protein in boundary layer. The above equation predicts the flux dependent increase of Rf with time, and can only be applied with a constant Cb.pr as in continuous system.

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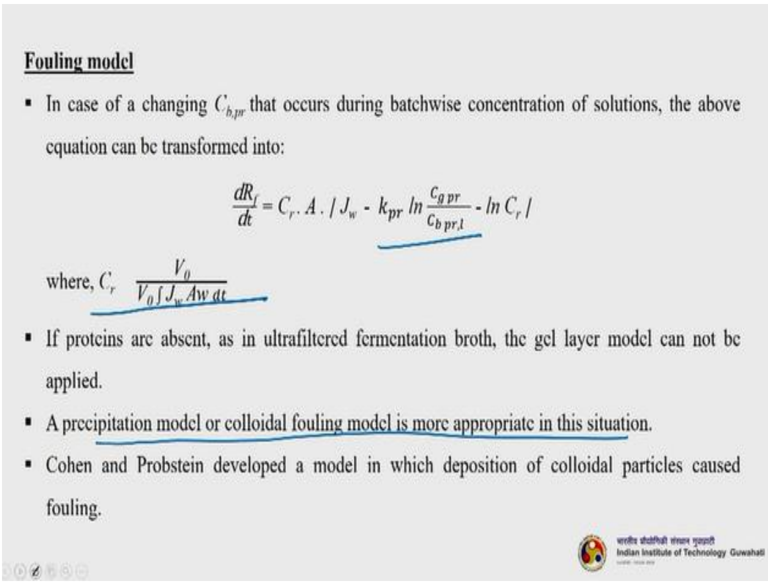

So, in case of a changing C b.pr that occurs during batchwise concentration of solutions, the above equation can be transformed into this particular equation, where dRf by dt equals to Cr into A into Jw minus, this particular equation minus ln Crl. So where Cr is given by this, this equation V0 by V the integration of this Jw. Aw. dt. So if proteins are absent, as in ultrafiltered fermentation broth, the gel layer model cannot be applied because it is not required, because there will be no gel formation, Okay? On the membrane surface.

So, a precipitation model or colloidal fouling model is more appropriate in this situation. So Cohen and Probstein developed a model in which deposition of colloidal particles caused fouling.

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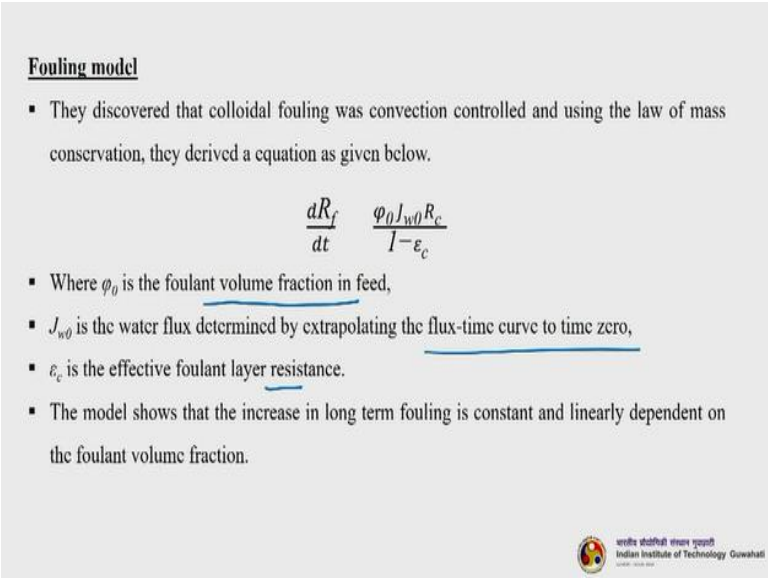

So they discovered that colloidal fouling was convection controlled and using the law of mass conservation, the derived a question as given below; so dRf by dt across to this Phi not Jw not Rc by 1- epsilon c. So we are find out is the foulant volume fraction in feed. Jw is the water flux determined by extrapolating the flux time curve to time 0, Okay? So basically it is the flux at zero.

So epsilon c is the effective foulant layer resistance and this model shows that the increase in long term fouling is constant linearly dependent on the foulant volume fraction.

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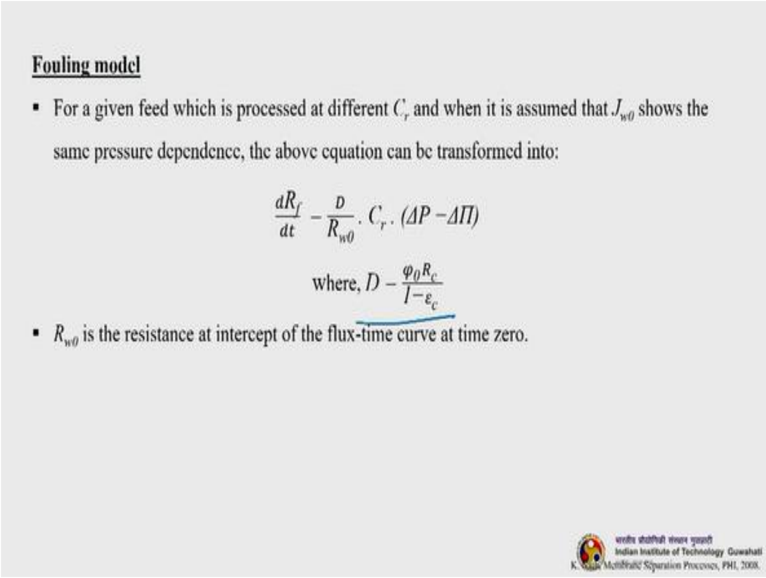

So for a given feed which is processed at different Cr and when it is a assumed that Jw0 shows the same pressure dependence, the above equation can be transformed into dRf by dt equals to D by Rw0. Cr. delta P - delta pi, where D equals to this Phi not Rc into 1- epsilon c. Rw0 is the resistance, is the resistance at intercept of the flux time curve at time equals to 0.

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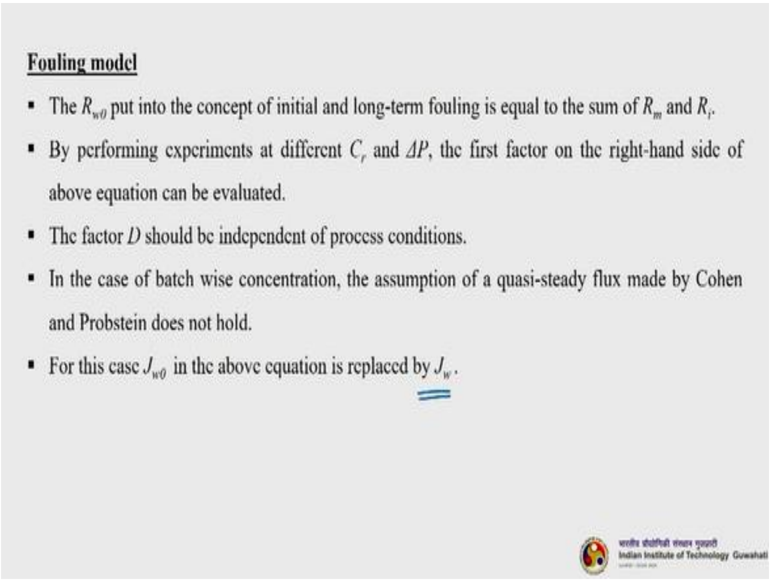

So, the Rw0 put into the concept of initial and long term fouling is equal to the sum of Rm and Rf. By performing experiments at different Cr and delta P, the first factor on the right hand side of the above equation can be evaluated. The factor D should be independent of the process condition. In the case of batch wise concentration, the assumption of quasi- steady state of flux made by Cohen and Probstein does not hold. For this case Jw0 in the above the question is replaced by Jw.

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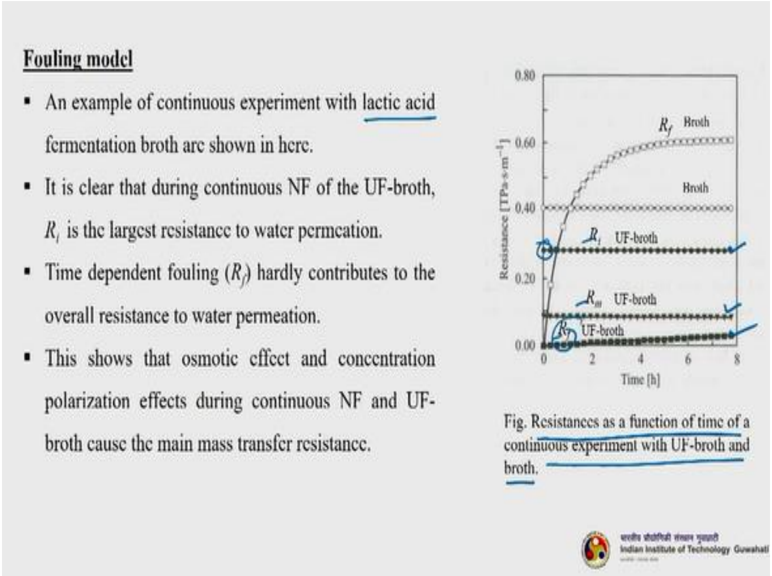

So, let us see this particular figure here. So this is a resistance as a function of time of a continuous experiment with the UF broth, and only broth, Okay? So UF broth means ultrafilter broth, Okay? So an example of a continuous experiment with lactic acid fermentation broth is shown here. So it is clear that the continuous NF of the UF-broth Ri is the largest resistance.

So this is the UF broth, this is UF broth, this is UF broth, this is UF breath, and this is for Ri, this is for Rm. This is for Ri, Okay? You can see this is for Rm, this is for Ri. So you can see this, so it is clear that during this, nanofiltration of the ultrafiltration broth Ri is the largest a distance where you can see, Okay? So time dependent fouling Rf hardly contributes to the overall resistance of the water permeation.

So Rf is almost negligible, so you can almost neglect the Rf, Okay? Now this shows that osmotic effect and concentration polarization effects during continuous NF, and UF broth cause the main mass transfer resistance, Okay?

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NF Membrane and Module

There are two types of membranes:

Spiral membranes, cheapest but more sensitive for pollution.

Tubular/ straw membranes, the most used membranes seen the costs and effect, shall not easily be polluted.

The surfaces from the filter determine the capacity from the filter. Spiral membranes have the biggest surface area in general and are therefore the most cheapest in use. The surface area from Tubular/ straw membranes is less in general.

The pre-purifying of the feeding water has a influence on the performance of the installation.

The need of pre purifying depends on the feeding water quality.

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So, NF membrane and module; so there are two types of membranes actually available commercially the spiral wound and the tubular membranes. Spiral membranes are cheapest but more sensitive to pollution. Tubular and straw membranes, the most used membranes seen the costs and effect, shall not easily be polluted. The surfaces from the filter determine the capacity from the filter.

Spiral membranes have the biggest surface area in general, and are therefore the most cheapest in use. The surface area from tubular or straw membranes is usually less in general. So the pre-purifying of the feeding water has influence on the performance of the installation. The need of pre-purifying depends on the feeding water quality.

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Difference between RO/NF

While RO and NF are very similar, **they can be distinguished based on the size of particulates that each is able to remove**. Comparatively, RO and NF are capable of removing finer contaminates than MF and UF, with applications including the removal of hardness, nitrates, sulfates, total dissolved solids (TDS), heavy metals, radionuclides, and organic macromolecules from process and waste streams.

RO	NF
extremely small pores capable of removing particles as small as 0.1 nm	slightly coarser filtration than RO, with the ability to remove particles as small as 0.002 to 0.005 µm
Old technology, since 1950	Recent technology
used chiefly for desalination, as in potable water generation from seawater or brackish water sources	developed mainly for potable water generation
very efficient at removing all ions, large and small	NF removes harmful contaminates, such as pesticide compounds and organic macromolecules, while retaining minerals that RO would otherwise remove. Nanofiltration membranes are capable of removing larger divalent ions such as calcium sulfate, while allowing smaller monovalent ions such as sodium chloride to pass through.

Courtesy: SAMCO

Indian Institute of Technology Guwahati

So let us now try to understand, before we wind up. What is the difference between RO and NF. So you know that we have discussed this that RO and NF, they are very much similar to each other, but they can be distinguished based on the size of the particulates or solute that each is able to remove.

So comparatively, RO and NF are capable of removing finer contaminantes than micro filters and ultrafilters, with applications including removal of hardness, nitrates, sulphates, total dissolved solids or TDS, heavy metals, radionuclides and organic macromolecules from process and waste streams. So, this is just this tabular format to try to understand the differences.

So RO is rejecting a small then having small pores. So they are capable of removing particles as small as 0.1 nanometer, but NF range is almost point 0.002 to 0.005 microns, Okay? So, RO is old techniques existing almost since 1950s. However, NF is a very recently developed technology. So RO was used chiefly for the, mainly for the desalination purposes, as in potable water from seawater or brackish water sources and NF is exclusively developed mainly for the potable water generation.

So RO is extremely efficient in removing all ions, large and small, and NF removes harmful contaminants such as pesticide compounds and organic macromolecules, while retaining minerals that RO would otherwise remove. So, Nanofiltration membranes are capable of removing larger divalent ions such as calcium sulphate, while allowing smaller monovalent ions such as sodium chloride to pass through.

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Technical Assessment of NF

Criteria	Description/Rationale
Status of technology	Mature & robust technology
Applications	Water softening, metals removal and produced water treatment
Feed water quality	TDS 500 – 12000 mg/L can be handled with high concentrations of divalent ions, multivalent metal ions and radionuclides
Product water quality	Depends on feed water quality & operating conditions. >90% rejection of larger divalent ions and metals Moderate rejection of monovalent ions
Recovery	Ranges between 75% - 90%
Pre-treatment of feed water	Required to reduce scaling & fouling
Post-treatment of product water	Required re-mineralization to maintain sodium adsorption ration (SAR) values
Energy use	Less energy than RO for same feed water quality
Chemical use	To prevent scaling and fouling, scale inhibitor and caustic may be required
Lifetime	3-7 years depending on use and operating conditions

So, this is a technical assessment of NF technology, so you can just go through it. So, the status of technologies, it is an expression is quite mature and it is a robust technology. So applications are wide, the most of the important applications are water softening, metal removal and produced water treatment. The feed water quality; it handles almost 500 to 12,000 milligrams per liter of a TDS. Okay? And product water quality; that depends on the feed water quality and operating conditions.

However, greater than 90% rejection of a larger divalent ions and metals are possible. Moderate rejection of monovalent ions are possible in nanofiltration. So the recovery range is almost 75% to 90%. This is one of the most important parameter. When you talk about industrial applications, the pre-treatment of feed water is necessary as we have learned in today's lecture. So it is required, so as to reduce scaling and as well as fouling.

Post treatment of product water sometimes required, especially we are talking about potable water because it is divided up all sorts of minerals. So re-mineralisation of sodium adsorption ratio that is SAR value is actually required. So energy uses quite less than the RO for the separate water quality. There is no chemical use however sometimes we use at the scaling and antifouling inhibitors, Okay? This is the caustic may be required.

And the lifetime depends actually, so it is anytime between 3 to 7 years, depending on use and operating conditions. So thank you very much.

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So today's lecture, mostly is taken by a taken from, from Professor Nath’s book, as well as some other journal sources. Please go through it and in the next class,

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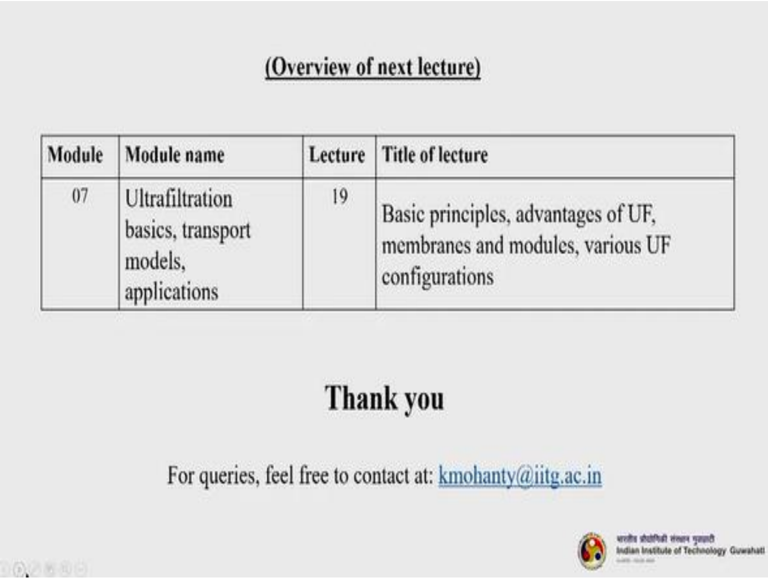

We are starting ultrafiltration, and the next module. So we will try to understand the basic principles and advantages of ultrafiltration, different types of membranes and modules that is required for the ultrafiltration, and various types of ultrafiltration configurations. So thank you very much. In case you have any queries, please feel free to write to me at kmohanty@iitg.ac.in. Thank you.