Thermal Processing of Foods
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Lecture 20:
Nanofiltration, Electrodialysis and Membrane separation

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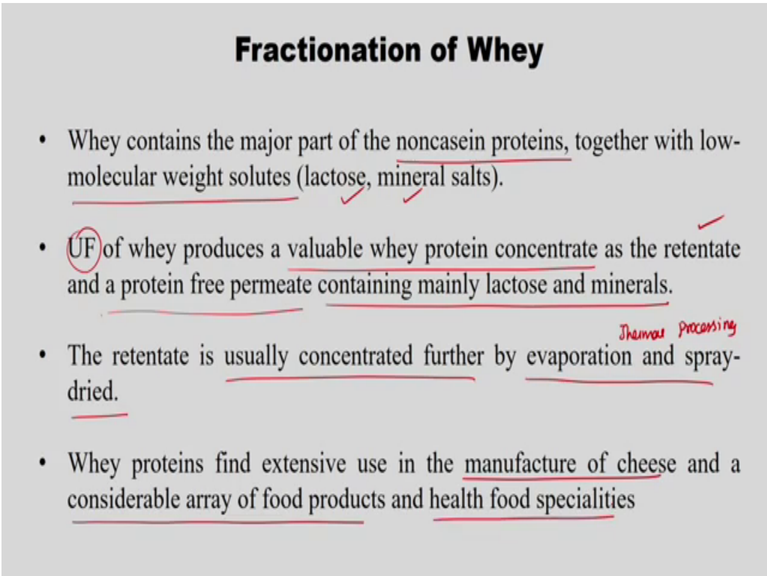

Good morning, one and all. So last two classes we have seen the membrane separation processes. In the first class, we have probably discussed about the various modules available and basics of membrane separation process in food industry where they are exactly used, in our second lecture. So we have seen specifically the four different membrane separation process which are nothing but micro filtration, ultra filtration, reverse osmosis and nano filtration.

And in the last class, we told that, where these five processes are being applied in food industry, in the general cases and applications and what are all the modules available for each membrane separation process everything we have seen. And also, we have in-depth discussed about micro filtration as well as ultra filtration. In the ultra filtration, we have ended our second lecture with the cheese making and fractionation of whey process.

So I will start from there with small recap of fractionation of whey and other applications of ultra filtration. And today's class, we are going to see about the nano filtration and reverse osmosis and also electrodialysis. If time permits, we will do two or three problems. Actually here I would like to mention about these, my membrane separation process, we are seeing it in application wise, right.

So, we are not going to do in-depth analysis of various membrane separation processes, because there are lot of modifications in it and there are a lot of theories and also we are not discussing anything on the mathematical side of it, mathematical modeling or the calculations regarding the membrane separation process. So we are mostly concentrating on the application side, in food processing industry.

So what are all the membrane separation process are being used and how do I choose the membrane for particular application, okay. So, but still we will do certain problems on how to find out the osmotic pressure and how to find out the retentate and permeate concentration that we will do, okay. So I will start with whatever we ended in the last class to make you remind few things.

So fractionation of whey using ultra filtration. So that was done by the retentate is nothing but noncasein protein and along with some low molecular weight solute, so, which are nothing but a lactose and mineral salts. So ultra filtration is used to fractionate this whey part, that is nothing but a valuable whey protein concentrate as a retentate and the protein free permeate which contains mainly lactose and minerals, lactose and minerals, these both comes in permeate and the whey protein is concentrated.

So the retentate is usually concentrated further, retentate is nothing but a valuable whey protein using a evaporation or spray-dried, the further thermal processing. So these two are thermal processing, okay. So instead of going directly from the noncasein protein part of the whey to evaporate or spray-dried, so if you use in between the membrane, so you can reduce the energy load which is being spent on evaporation or spray-dried. So these are all thermal processes, okay. So then further these whey proteins are used for manufacturing of cheese and considerable array of food products and health food specialties.

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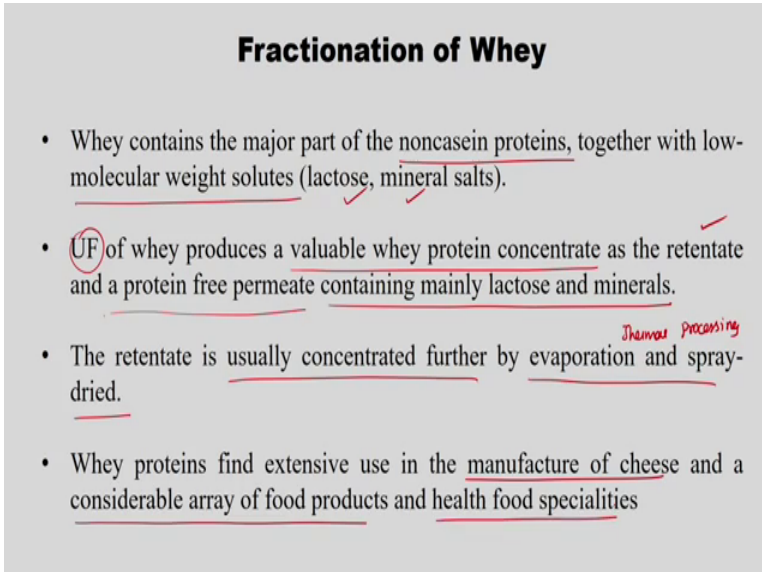

So the process goes like this, the pretreated pasteurized whey, so which is being fed into micro filtration membrane. So from there we get the fat or curd residues, then the permeate goes for another process which is nothing but ultra filtration. So here is what the main process is being done, then the permeate is collected and the retentate is further added with a diafiltration water.

So this diafiltration probably I have told you in the last class itself, the diafiltration also they use it as a separate membrane process. So which is nothing but, I will take the retentate, retentate of ultra filtration and add some water and further go for another ultra filtration module. So this is nothing, but a diafiltration. So we add the diafiltration water in the retentate which comes from the first ultra-filtration module.

Then further the permeates are getting collected as a lactose recovery, which is nothing but a purified concentration and spray-drying. So, this lactose further fed into these processes, either spray-drying or evaporation process. So then the retentate is nothing but a whey protein concentrate, right. So the permeate from the micro filtration comes into ultra filtration, so the retentate is taken and the diafiltration water is added into that and it goes for further ultra filtration, the retentate after second ultra filtration is nothing but a whey protein concentrate, the permeate is further purified and concentrated and go for spray-drying to remove the lactose.

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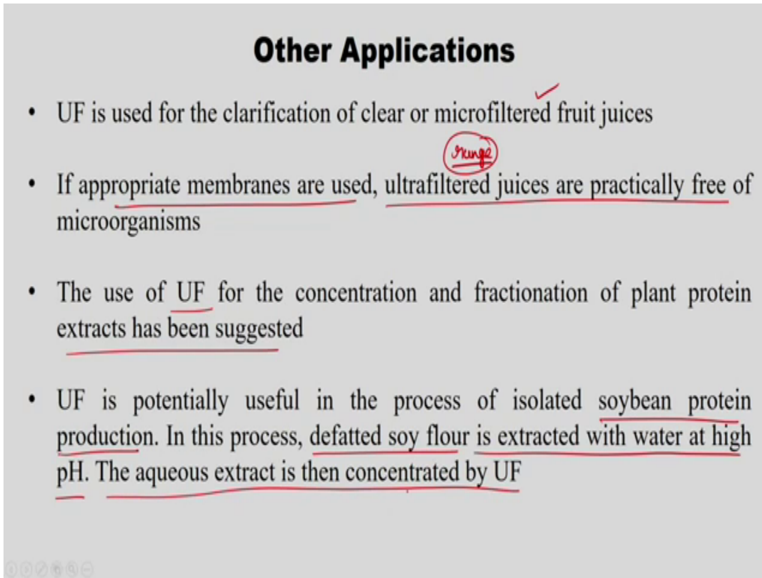

So the other applications of ultra filtration is used to for clarification of clear or microfiltered fruit juices and if appropriate membranes are used. So the ultra filtration also we have given the ranges, right. So the range of pore size and range of the pressure applied also, right. So if the appropriate membranes are chosen between the range where my micro organisms get filtered, then this ultrafiltered juices are practically free of microorganisms, right.

So the range, the pore size range what I have to choose is, so, that should be able to retain the microorganism, if that is the case, so, we call it as a cold pasteurization or cold sterilization, without applying the thermal processing. So the use of ultra filtration for the concentration and fractionation of plant protein extracts also suggested. So the ultra filtration membranes we use to concentrate and fractionation of plant protein. So one such case is soybean protein production, so, the ultra filtration membrane is use. So in this defatted soy flour is extracted with the water at high pH. So, the aqueous extract is then concentrated by ultra filtration.

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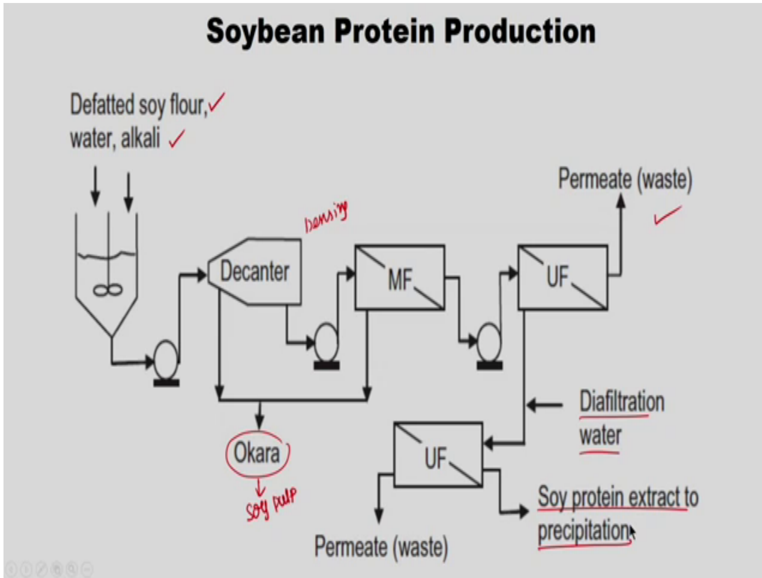

So the processes here, so, first defatted soy flour and then one alkali and water, this is fed into the tank. So this is further pumped to the decanter. So, decanter does the separation based on the density. So the high density, high density part of the feed is getting collected in the bottom, the clear upper part will further pumped into the micro filtration module. So the concentrated part we call it as a Okara. So this is nothing but a soy pulp, right.

So the further the clear, the upper portion will be further fed into the micro filtration then the permeate is further sent to the ultra filtration. So from the ultra filtration, we collect the permeate as a waste, then the retentate is further added with the diafiltration water and further concentrated using the ultra filtration. So, the permeate is goes as a waste, the retentate is nothing but a soy protein extract, so, which goes further for precipitation.

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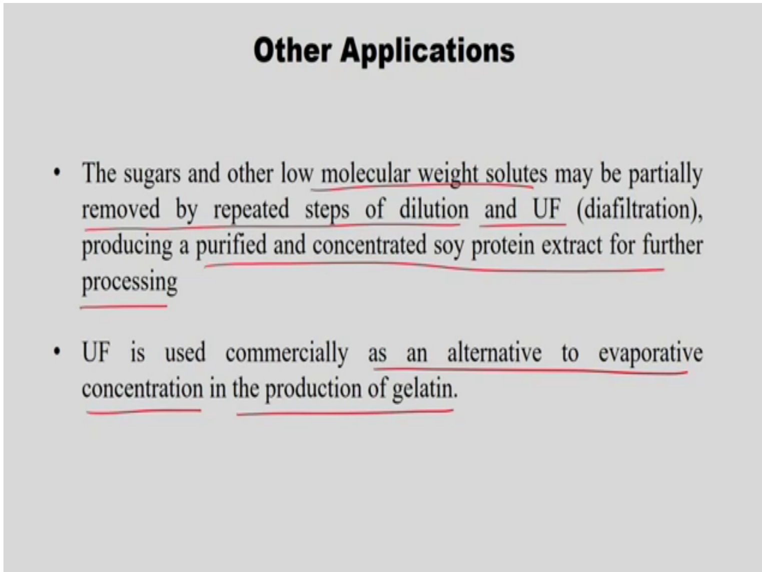

The other applications of ultra filtration is the sugar, actually here itself. So, this is we have used to twice, right, the ultra filtration module. First we remove the permeate and take the retentate and add the diafiltration water then further we go for ultra filtration, we collect the permeate and retentate. So this also further you can do more two or three times. right.

So the sugars and other low molecular weight solutes may be partially removed by repeated steps of dilution and ultra filtration so, that is nothing but a diafiltration, dilution and further ultra filtration which is nothing but a diafiltration, so, this we continue these steps and produce the purified and concentrated soy protein extract for further processing.

So this also can be done, so, the soy protein extract at what percentage you want it. So based on that number of you, ultra filtration modules can be added further, okay. So, the UF first used commercially as an alternative to evaporative concentration in the production of gelatin as well. So for this gelatin production also this ultra filtration membrane is used as an alternative to evaporation.

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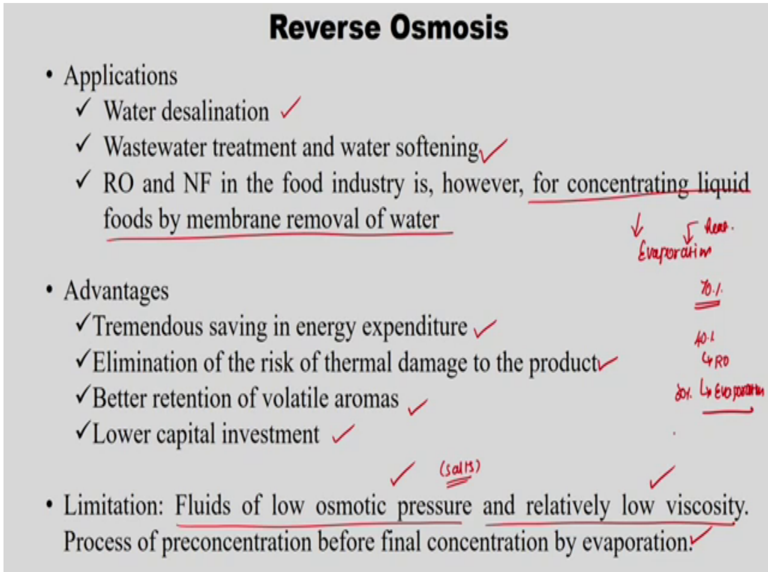

So today we mostly concentrate on reverse osmosis and nano filtration. So, most these, both techniques have much of overlap. So I will tell what is the exact difference in couple of slides after. So the reverse osmosis, the major application is water desalination, so this we are all know, the moment we say the reverse osmosis so, the first thing comes into our mind is water desalination and wastewater treatment and water softening, water softening is nothing but ions removal, the unwanted ions removal from the water.

The RO and NF in the food industry is however for concentrating the liquid foods by membrane removal of water. So reverse osmosis, water desalination most of the applications are related to wastewater treatment, but here in food industry, so where we use reverse osmosis is nothing but to concentrate the liquid foods by membrane removal of water, by removing water how do we concentrate.

So this can be done by the evaporation as well. So to do by evaporation, I need to add the heat, right. So, but here with the membrane itself by applying the reverse osmotic pressure, I can remove the water from the liquid food, right, to concentrate them further. The advantage is tremendous saving in the energy expenditure as I told, so the heat is not being applied here and elimination of the risk of thermal damage of the product.

Obviously, if you are not using the heat for processing then you can avoid the thermal damage and better retention of volatile aromas. Since we are not applying the heat, the volatile aromas gets retained, so, then your food also looks fresh, then lower capital investment. So we are not investing anything large on this part because it is just a membrane process. We don't need to imply any heat transfer requirements, that is why the lower capital cost.

And the limitation wise, fluids of low osmotic pressure and relatively low viscosity. So in the reverse osmosis, because you are applying the pressure against the osmotic pressure, so this processes can be applied only for fluids with the low osmotic pressure, that means salts, most of the time salts cannot be handled because they have a high osmotic pressure compared to other materials and a relatively low viscosity product only can be handled. And the process of preconcentration before final concentration by evaporation.

This is not a limitation. So this is a advantage, right. So before going for evaporation. So, for example, I need to have some 70 percentage of this concentrated solids. So I can do up to 40 percentage using any RO and after that remaining 30 percentage can be done by, remaining 30 percentage can be done by evaporation, okay. So in that case, so you are reducing the energy load which is given if we go for directly evaporation.

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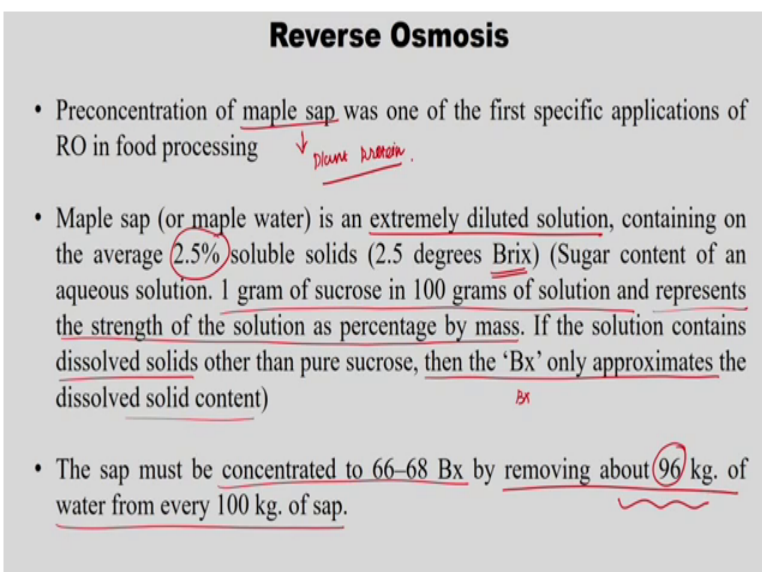

And preconcentration of maple sap was one of the first specific applications of RO in food processing industry. So this is nothing but a plant protein, okay. So when the reverse osmosis was tried in the food industry, the first one, the preconcentration was done on the maple sap. So this is maple sap or maple water because it is a extremely diluted solution containing an average of 2.5 percentage soluble solid.

So that means 2.5 degrees of Brix. This is a unit, right. So the sugar content of an aqueous solution, right, 1 gram of sucrose in 100 grams of solution and represents the strength of the solution as a percentage by mass, right. So 2.5 percentage soluble solids that I can express in terms of 2.5 degrees Brix. So this is nothing but a 1 gram sugar in 100 grams of solution, so that is nothing but 1 Brix unit, okay.

So, if the solution contains dissolved solids other than pure sucrose then Bx only approximates the dissolved solid contents, okay. So the unit is Bx which is nothing but a Brix, okay. So this is just to tell you about the unit, but what we are discussing is the maple sap which is an extremely diluted solution containing and an average of 2.5 percentage soluble solid.

So where, how the reverse osmosis is being used to concentrate this maple sap that is what the process is, the sap must be concentrated to 66 to 68 Bx. So that means 66 percentage of the soluble solids is being concentrated using a reverse osmosis by removing about 96 kg of water from every 100 kg of sap, remember, almost 96 kg of water which contains in the 100 kg of sap, right. So this is a huge quantity of water 96 kg from me every 100 kg of sap.

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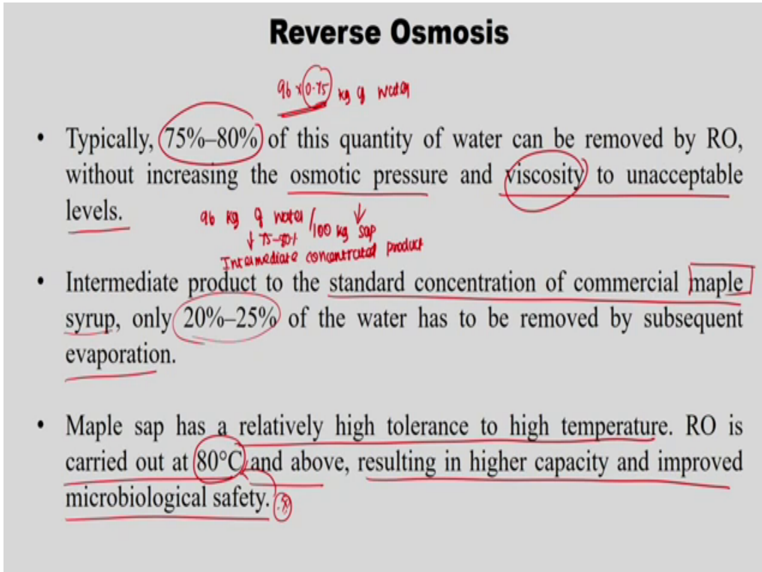

So typically. so 75 percentage to 80 percentage of this quantity of water can be removed by RO. So that means 96 kg I am having, so in that, almost 75 to 80 percentage of water, kg of water can be removed by using what, reverse osmosis, then further amount of water can be removed using evaporation or drying, okay. So the without increasing the osmotic pressure and viscosity to unacceptable levels.

So one may think, okay, 96 kg of water can be removed, why can not we do in reverse osmosis at one go, right. So, but what restricts me to do so is the osmotic pressure and viscosity, right. So when you remove the water, the soluble solids gets concentrated, so the viscosity should not go unacceptable levels, so that in that case, I may not be able to apply the reverse osmosis.

The same way, when you concentrate further and further, the osmotic pressure also gets increased, right. So you need to push them again the membrane surface. So in that case, so, these two are limiting parameters which limits me. So how much percentage of the water from 96 kg of water can be removed, so that, these two based on osmotic pressure and the viscosity of the solution then 75 to 80 percentage of the 96 kg of water is removed.

The intermediate product, intermediate product in the sense, first we have told here, so it is almost 96 kg of water per 100 kg of sap. So in this, I will remove, I removed 75 to 80 percentage of the water using RO, so the remaining product we call it as a intermediate product, intermediate concentrated product, so intermediate concentrated product, okay. So this is intermediate product to the standard concentration of commercial maple syrup.

So only 20 to 25 percentage of the water has to be removed by subsequent evaporation. So the maple syrup is highly concentrated one, okay. So what we are doing here maple sap, which is nothing but a 2.5 percentage of the solid content. So that is being processed using membrane separation which is nothing but RO and evaporation to get the maple syrup. So in that RO part is almost 75 to 80 percentage of 96 kg of water per 100 kg of sap.

The maple sap has relatively high tolerance to high temperature, so in that case, RO is carried out at 80 degree centigrade and above, resulting in higher capacity and improved microbiological safety. So this food is tolerant to temperature, so the RO process is carried out at higher temperature which is nothing but 80 degrees centigrade. So which gives us the microbiologically safe food with higher capacity.

And one must also be careful, because the membrane separation process we are doing it only to fold one is to reduce the energy consumption and if my food has the large particulate solids then how to handle, so for that purpose also we move to membrane separation. The other advantage is since we are not using the high temperature process, my volatile aromas get retained, right, and also nutritional quantity.

So here we are mainly concentrating on the microbial safety that is why we are going for 80 degrees centigrade and one must ensure at this temperature the nutrient quality as well as the volatile aroma if the food is of having these two advantage or if the food is having a lot of volatile aroma or nutrient content. So we need to think about why we are processing at this high temperature of 80 degrees centigrade, that is what probably we are doing it in thermal processing as well.

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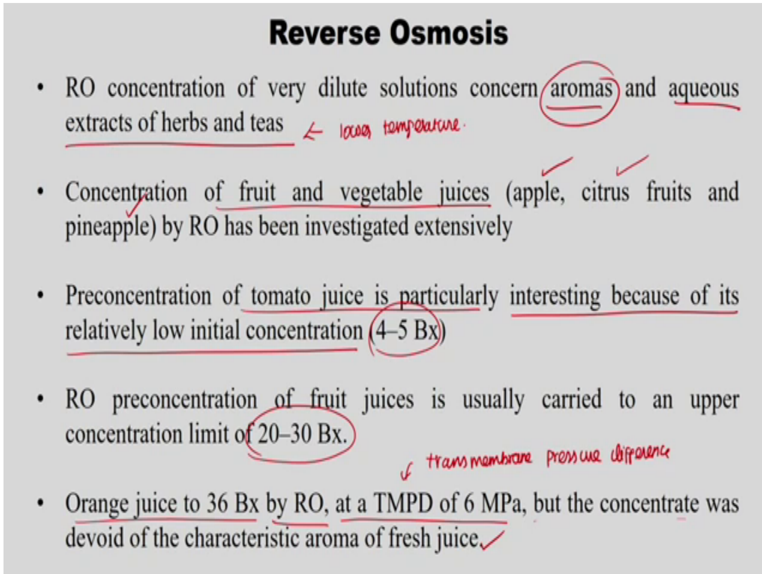

So the RO concentration of very dilute solutions concerns aromas and aqueous extracts of herbs and teas. So in this case, so the RO is applied for to retain the aromas as well as when we process the extracts of herbs and teas so we need to be processing at lower temperature, okay. So that is way my choice is RO to get the aqueous extracts of herbs and teas. And concentration of fruit and vegetable juices, mostly apples, citrus fruits and pineapple, there also RO has been investigated, the process of RO has been investigated extensively.

And pre concentration of tomato juice is particularly interesting because of its relatively low initial concentration, so which is about 4 to 5 Brix. So here we are mainly concentrating the tomato juice using RO, so instead of going for evaporation. And RO pre concentration of fruit juices is usually carried to an upper concentration limit of 20 to 30 Brix, right. So here the pre concentration is done using RO, the final concentration is done using evaporation or drying technique.

The same way orange juice to 36 Brix by RO at a TMPD of, TMPD is nothing but trans membrane pressure difference, okay. So the orange juice to 36 Brix by RO at a TMPD of 6 mega pascal, but the concentrate was devoid of the characteristic of aroma and fresh juices, this is what I just mentioned, right. So we can go for higher temperature and higher concentrations and also we need, which restricts me is to go for a higher concentration, one is osmotic pressure and the viscosity of the product, but if we process at higher temperature, I feel like that is microbiologically safe, but the thing is we also look into what happens to the characteristic aroma of the food product, right.

So the more and more temperature you go, that the aroma will get decreased, so that is the reason I choose RO, right. So when you choose RO to concentrate any liquid product to pre concentration, so these are all the important and critical factors we need to also keep in mind. So if I go for higher temperature process, what happens to volatile aroma and if you are going for a higher concentration, so how much osmotic pressure I need to apply and what is the viscosity of the product. So this restricts me, so what temperature I need to process my reverse osmosis or what concentration I need to choose for pre concentration of liquid food.

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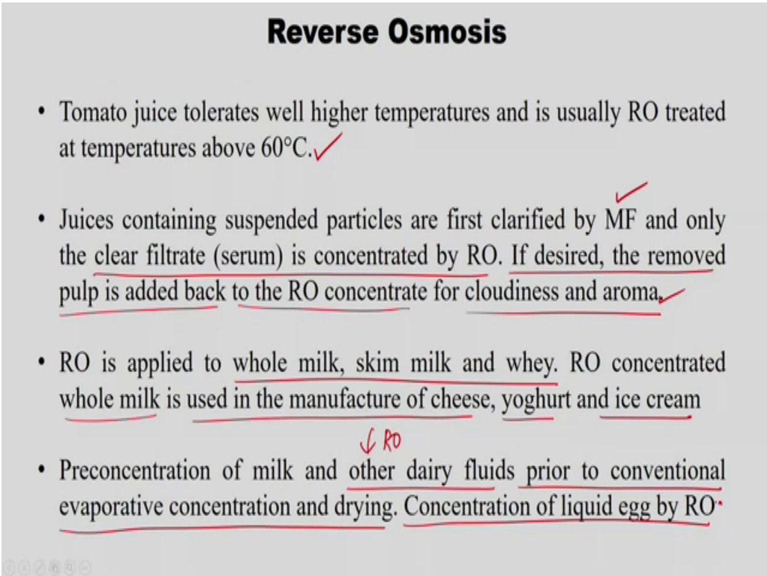

The tomato juice tolerates well high temperatures and usually RO treated at temperatures above 60 degree for tomato juice. The juices containing suspended particles are first clarified by micro filtration and only the clear filtrate or serum is concentrated by RO. If desired, the removed pulp is added back to the RO concentrate for cloudiness and aroma, right. So even for ultra filtration, this is what we have seen, right. The first the juices or any product, any food product, what we do is we first clarify it using a micro filtration then we are sending to ultra filtration, here also same way.

So the suspended particles are first clarified using micro filtration then fed into RO process. So if desired removed pulp is added back, removed pulp in the sense, the, whatever you removed from the micro filtration can be added after the reverse osmosis process to get the aroma and fresh taste, okay. So the RO is applied to whole milk, skim milk and whey, so milk processing also RO is being applied. RO concentrated whole milk is used in the manufacture of cheese, yogurt and ice cream.

So for these manufacture cheese, yogurt, ice cream manufacturing, the concentration of whole milk can be done using reverse osmosis process as well. The pre concentration of milk and other dairy fluids prior to conventional evaporative concentration and drying. So the pre concentration of milk and other dairy fluids so prior to conventional evaporative concentration and drying, the RO is being used and concentration of liquid egg by RO is also reported.

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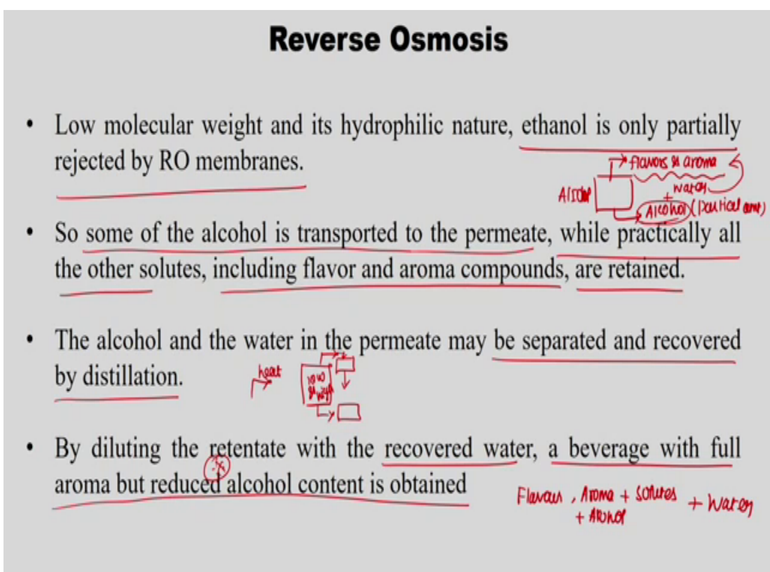

The lower molecular weight and its hydrophilic nature, the ethanol is only partially rejected by RO membranes, right. So the ethanol concentration also can be done using a reverse osmosis membrane, but here due to low molecular weight also it is hydrophilic nature restricts the RO membrane in ethanol concentration, because what happens is, the ethanol is partially rejected and your permeate also will have the ethanol component, right. So some of the ethanol is transported to the permeate, while practically all other solutes including flavor aroma compounds are retained.

So when you process the alcohol with the RO membrane, right, so the retentate is, retentate here is flavors and aroma, the permeate is nothing but will have alcohol as well, permeate will also contain partial, partial amount, okay. So the alcohol and water, the main is the permeate component is water. So the water plus alcohol in the permeate may be separated and recovered by distillation to remove the alcohol component so that diluting the retentate with the recovered water, a beverage with the full aroma but reduced alcohol content is obtained.

So whatever we got as a retentate here, so that will be added with the water, right. So the retentate includes the solutes, flavors and aroma, the permeate includes alcohol and water. So this alcohol and water component further distilled, distillation is nothing but another thermal processing only, so we apply the heat, right. So here you have a low boiling as well as high boiling mixture.

So the low boiling one will get the, will get evaporated first and gets collected as a condensate, the higher boiling one will come later, right, or taken as a bottom product, okay. So that is the way I separate the alcohol and water. This water separated water from the permeate again added into the retentate which has the solutes, flavors and aroma. So this is the partial amount of alcohol is already removed, right.

So that means the one what I prepare now is a beverage with the full aroma, but reduced alcohol content, right. So what I have is? The flavor, flavor component, aroma, plus some solutes and also the alcohol is also there, partial alcohol, because the partial alcohol only goes into permeate, right. So in the permeate, I will have water and alcohol, further it is distilled to remove the water so that water is fed back, so that means some of the alcohol went into permeate. So that I am not adding, the beverage now contains only the aroma and solutes without much alcohol content, so that means reduced alcohol content.

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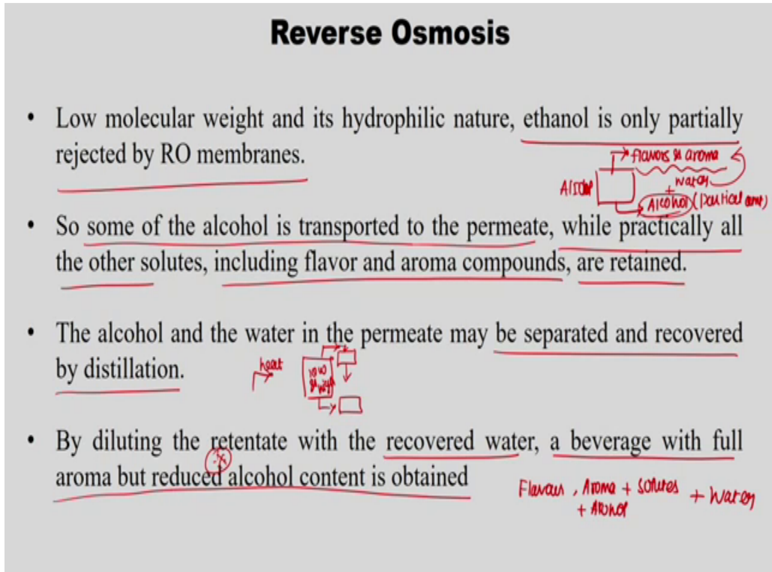

So now the admixture of the recovered alcohol to the original beverage results in a product with increased alcohol content. So what I did, so here in the distillation I removed the water and alcohol, the water I have went back and added in the retentate, so the removed alcohol can be added into the original beverage and the product will be having higher or increased alcohol content, the original product, right, original product will have certain alcohol content, if this alcohol is also added.

So that particular beverage contains the higher amount of alcohol content. Another application of RO is in the wine industry is the concentration of grape must. So the grape must is the fresh juice, which is not brewed, so the fresh juice which has the fruit pulps also. So the concentration of grape must also the RO is used. So RO and NF are being increasingly used for the pre concentration of thin juices and the production of sugar from the beet and cane, right.

So then we produce the sugar from sugar cane, so there also the RO and NF process are being used to pre concentrate the thin juices and condensate of evaporators. So evaporator we have seen, right, so we take the dilute solution and we apply heat, right, so the water gets evaporated, right. So when you further condensed that water, so that is called evaporator condensate, right. So the condensate of evaporators are not pure water, but containing varying amount of organic matter. So when the water evaporates, it also carries some of the organic matter we cannot say that is a pure water.

So the treatment of these condensates by RO or NF helps recover important quantities of high quality water and reduces the cost of water disposal. So what did we say? The, whatever the condensate, whatever the vapor comes out of the evaporator, we condensate, so that is called evaporator condensate. So this also has some of the organic matter because whatever the material I am processing in the evaporator which may have organic matter.

So when the water evaporates it also carries with some of the organic matter with it. So because of that, the condensate whatever I am getting from the evaporator, so that is not of pure water, right. So this condensates after cool, it is sent to the RO or nano filtration membrane, so which removes those organic matter and produces the high quality water, right. And one thing is I am getting high quality water, another point of view in the cost effective matter, I am also reducing the cost of waste disposal.

So that means, so if you have to throw this condensate with all organic matter, you have a certain environmental regulations, right. So that is not that easy process. So you are also getting the high quality water and also you are reducing the cost of waste disposal. So this particular process is called condensate polishing, right, the condensate polishing. So there my RO and nano filtration membranes are being used.

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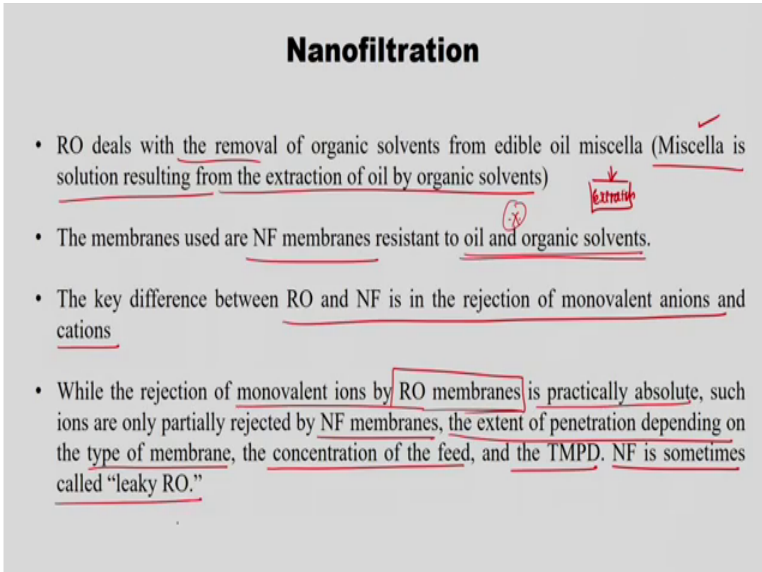

So now nano filtration. So certain applications I also told commonly for RO as well as nano filtration. So now, we are going to see what is exactly the difference between the reverse osmosis as well as nano filtration. So the RO deals with the removal of organic solvent from edible oil Miscella. So the Miscella is nothing but solution resulting from the extraction of oil by organic solvent. So that is nothing but a Miscella, it is used in the extraction of oil, right.

So extraction of oil is done using the organic solvents. So whatever the solution you get that is nothing but a Miscella. So the RO deals with the removal of organic solvent. So the Miscella contains the organic solvents as well as whatever the component to be removed from the oil. So to remove the organic solvents from the edible oil Miscella, the RO is being used.

So in the same process nano filtration membranes also can be used because the membranes used here are nano filtration membranes resistant to oil and organic solvents, the apt one to be used instead of RO is nothing but nano filtration membrane. So that means, the particular application, particular application of removal of oil from organic solvents, so we can use RO as well as nano filtration. So if you see before here also we are using RO or nano filtration to polish the condensate, right. So that means what is the difference between them, why they can be used interchangeably, right.

So the key difference between RO and NF is nothing but a rejection of monovalent ions and cations, right. So the key difference between reverse osmosis and nano filtration is nothing but a rejection of monovalent non ions and cations, while the rejection of monovalent ions by RO membrane is practically absolute. So absolute means the RO membranes removed completely monovalent ions, but your nano filtration membranes rejected them to the particular extent only.

So it cannot reject the monovalent ions fully, rights. So this depends the partial removal of the monovalent ions based on the extent of penetration depending on the type of membrane, concentration of the feed and TMPD, right. So why it is partially removing the monovalent ions is because of these three major factors.

So the partial amount, right, whether it is a 10 percentage, or 20 percentage, or 30 percentage, so the percentage of removal or extent of monovalent ions removal is based on the type of membrane we use and the concentration of the feed under trans membrane pressure difference. So because of that nano filtration is sometime called as leaky RO, leaky RO in the sense, RO could retain monovalent ions, but nano filtration could retain them partially because of that it is called leaky reverse osmosis process.

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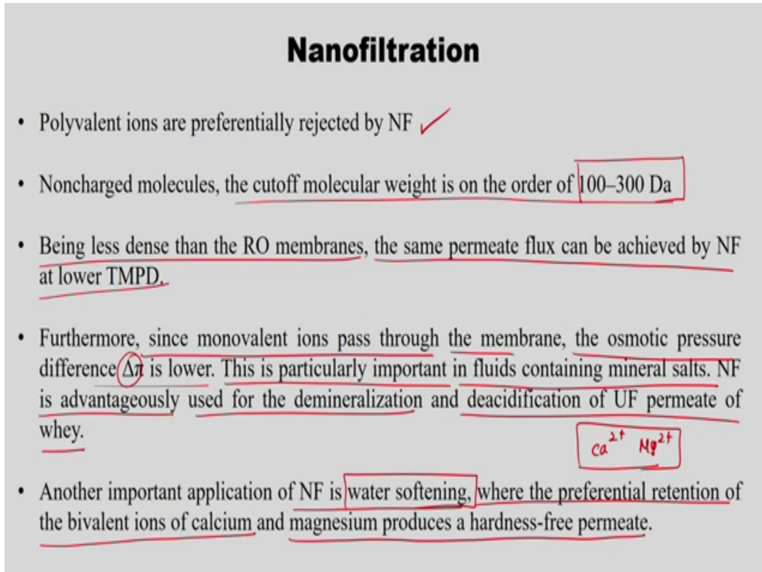

The polyvalent ions are preferentially rejected by nano filtration, for non charged molecules, the cut off molecular weight is on the order of 100 to 300 Daltons. The being less dense then RO membranes, the nano filtration membranes are less dense compared to RO membranes. The permeate flux can be achieved by nano filtration at lower TMPD, right. The same permeate flux can be achieved by nano filtration at lower TMPD because what we are doing now is, we are comparing just reverse osmosis and nano filtration.

So nano filtration membranes are less dense compared to RO membranes. So to get the same permeate flux by nano filtration, I can apply only lower TMPD compared to the reverse osmosis process. Furthermore, since monovalent ions pass through the membrane, the osmotic pressure difference, which is nothing but a Del-Pi is lower in nano filtration membrane compared to reverse osmosis. So this is particularly important in fluids containing mineral salts because we have already told for mineral salts osmotic pressure is high.

So when we process the mineral salts through nano filtration membrane, so the process can be done at lower osmotic pressure difference. The nano filtration is advantageously used for demineralization and deacidification of UF permeate of whey, right. So whatever the permeate we get it from the ultra filtration membrane, so that can be further deacidified using nano filtration, right. The permeate of whey which comes out of the ultra filtration can be further deacidified using nano filtration membrane.

Another important application of nano filtration is water softening, where the preferential retention of bivalent ions of calcium and magnesium produces hardness free permeate. So, CA2 plus MG2 plus, this bivalent ions are removed from the water using nano filtration, that is called water softening. So, if you remember in the earlier slide itself I told, right, the water softening is nothing but the hardness of the water is removed, so the hardness mainly comes from the bivalent ions which is nothing but calcium 2 plus and magnesium 2 plus ions. So that is being removed using nano filtration.

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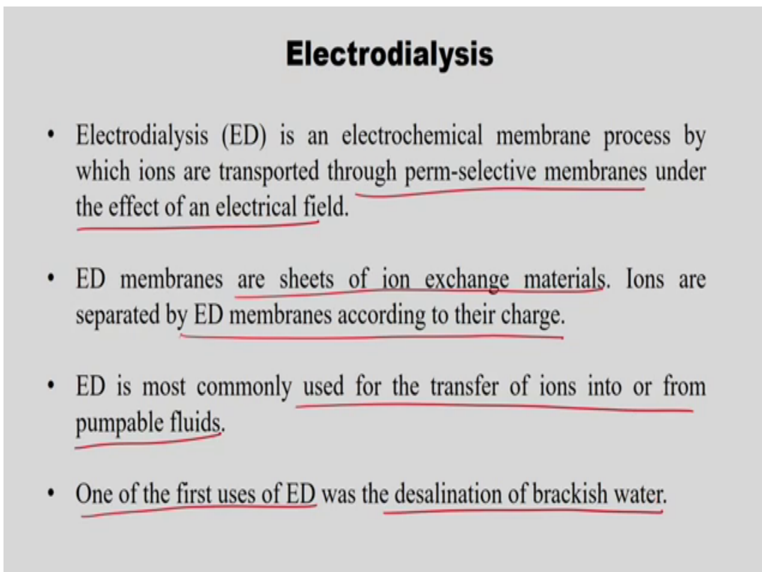

So the last one is electro dialysis, till now we have seen ultra filtration, first micro filtration, ultra filtration then reverse osmosis and then nano filtration. So nano filtration and reverse osmosis can be used interchangeably, but nano filtration has certain advantages over reverse osmosis, but remember the monovalent ions are partially removed using nano filtration, but that is completely removed using reverse osmosis.

So based on your application, you had to choose though nano filtration choose some of the advantages over reverse osmosis, we supposed to choose based on the process what we are going to apply, what membrane process to be chosen. The electrodialysis is an electro chemical membrane process by which ions are transported through the perm-selective membranes, through perm-selective membranes under the effect of an electric field, right.

So electric field is a driving force here, it is an electro chemical membrane process by which ions are transported through perm selective membranes under electric field. Electro dialysis membranes are sheets of ion exchange material. So the ion exchange material is nothing but it exchanges particular ions only. The ions are separated by ED membranes according to their charge, right, whether it is anion or cation. So ED is most commonly used to for the transfer of ions into or from the pumpable fluids, right.

So whether to remove the ions or add the ions, add the ions in the sense, in food processing, sometimes we told right, so if there is any nutrient quality is deficient so we can also add them during the process to get the particular nutrient level. So their one of the application maybe the addition of ions, ionic components. So ED is most commonly used for the transfer of ions into or from the pumpable fluids. One of the first uses of ED was the desalination of brackish water. So the water desalination only the first electro dialysis was applied.

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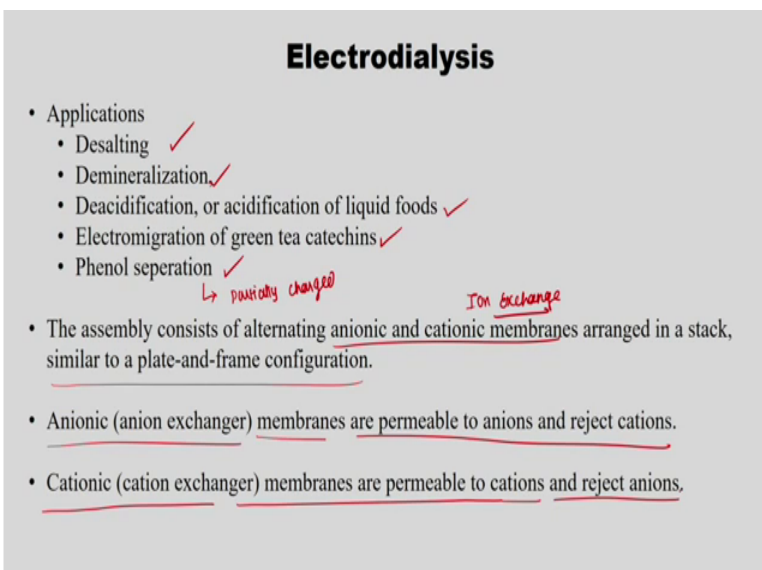

The application wise, desalting and demineralization, deacidification or acidification of liquid food, so deacidification you are supposed to remove the ions, acidification you are supposed to add ions. So that is what here we meant and electro migration of green tea catechins and phenol separation, phenol is also nothing but partially charged, okay. So we can use ED process for phenolic component separation as well.

The assembly consists of alternating anionic and cationic membrane, so these are nothing but an ion exchange membrane which permeate only particular ion arrange in a state similar to the plate frame configuration, plate frame membrane module we have already seen. The anionic or anion exchanger membranes are permeable to anions and reject cations, the cationic or cation exchanger membranes are permeable to cations and reject anions, okay.

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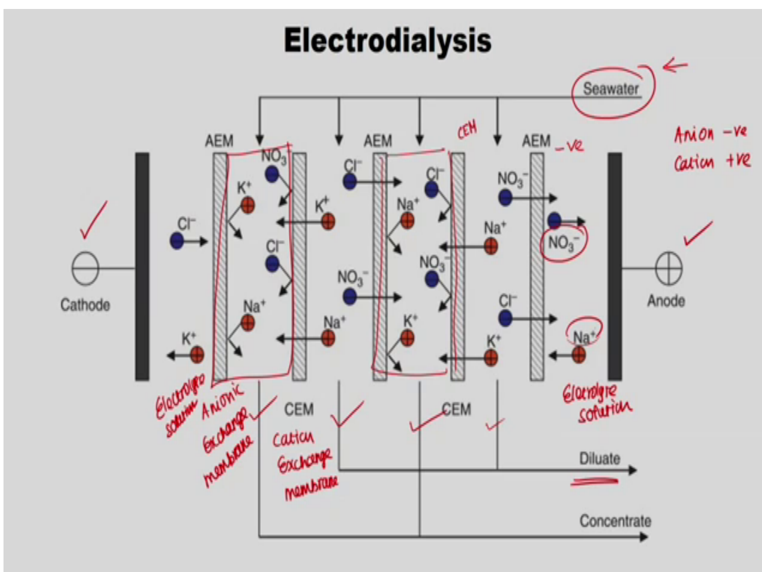

So here is the diagram. So the example here it is taken as a sea water. So, this AEM is nothing but anionic exchanging on anionic exchange membrane, so CEM is cation exchange membrane, okay. So that your anion and cation exchange membrane is stacked in a alternative manner. So your seawater is being fed into in between two anionic and cationic exchanging membrane. So here you have a anode which is nothing but a positive electrode, here we have a cathode which is nothing but a negative electrode. The feed, right, so here we have seen as a example, as we have taken seawater as an example, but this can be your fluid particles as well.

So if you see your electrode is not being in touch with the product whatever you are using for the separation, okay. So here the electrolyte solution is being used, electrolyte solution is used in both the places, electrolyte solution, okay. So now first we will see, so here electrolyte solution, so this is Na plus and so this is NO3 minus, blue one is NO3 minus, the red one is Na plus ions. So the anion is nothing but a negatively charged, the cation is nothing but positive, right. So the anion tend to accumulate near the anode because it is a positive electrode, the cations tend to accumulate near the cathode which is a positive ion, so the anion pass through anion exchange membrane.

The cations pass through cation exchange membrane. So when you are feeding the seawater here. So the NO3 plus and Cl minus tend to pass through the anionic exchanging membrane, so which allows the negative charge, right. The same way Na plus and K plus, the positively charged ions pass through the CEM, right. So then it gets concentrated in this particular space. Why? Because the when the cations moves here, so it has a cation exchanging membrane.

So when the anion moves this side, it will not allow further, so the Na plus and Cl minus gets accumulated here, then if you see the next compartment, the NO3 passes through the anion exchange membrane, and K plus and Na plus will pass through the cation exchange membrane, then here in this particular space, they get concentrated. So this is the way we collect the concentrate from this, this and you have a dilutant, which is free of ions right because the ions moved through the ion exchange membrane.

So you collect the dilute, okay. So this is the electro dialysis process. So you have two ion exchange membranes which passes specifically either anion or cation. So the anion pass through the anionic exchange membrane and gets collected near the anode and cation pass through the catatonic exchange membrane and gets collected near the cathode.

And also remember, your product is not being in touch with the electrode because that will be taken care by the electrode solution. So from this, wherever the concentrators concentrated we collect the concentrate which is nothing but a salt particle, organic salts and wherever the salts is removed, so that is nothing but a dilute, so if you want pure water, so the dilute is nothing but your pure water.

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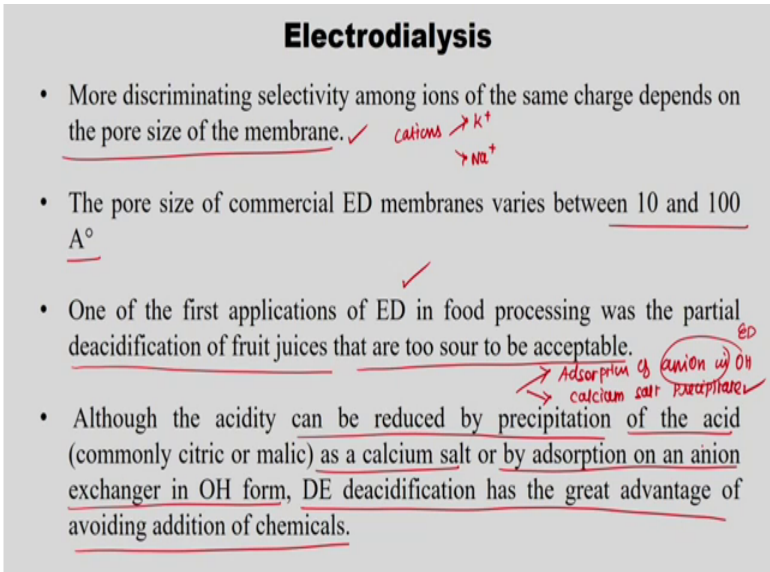

So the more discriminating selectivity among ions of the same charge depends on pore size of the membrane. So what we have seen here is, so I have taken two molecule, right, Na plus and K plus, right, in terms of a cation. So if I want to remove only Na plus, so that can be done by the pore size, right. Based on the pore size, I can remove even from same cations.

So I can further differentiate them into K plus, Na plus by taking care of the pore size of the membrane, whether only K plus to be removed or Na plus to be removed. The pore size of commercial ED membranes varies between 10 and 100 A°. And one of the first applications of ED in food processing was the partial deacidification of fruit juices that are too sour to be acceptable, right.

If the acid content is more, we feel that sour taste. So to remove the acid component or deacidification of fruit juices, the ED was first employed in the food processing industry, although the acidity can be reduced by precipitation of the acid. So commonly citric or malic acid, as a calcium salt or by absorption on an anion ionic exchanger in OH form, the DE, DE is nothing but the electro dialysis, deacidification has the greater advantage of avoiding addition of chemicals.

So the thing is, the deacidification in earlier also before applying ED, the deacidification in industries were done by either one of these mechanism. One is, the precipitation of acid using the calcium salt and or absorption of an anionic exchanger in the OH form, right. So, both the ways the deacidification can be done, but still the ED deacidification has the greater advantage because we are not adding any chemicals here, right.

So that is the way the ED is advantageous one compared to commercial precipitation of acid using the calcium salt. So here the acidity can be reduced in two ways, one is, absorption of anion in OH form, so other way is adding calcium salt, okay, and precipitate, okay. So this is conventionally followed, but when you apply ED here, right, that is advantage compared to normal precipitation using calcium salt.

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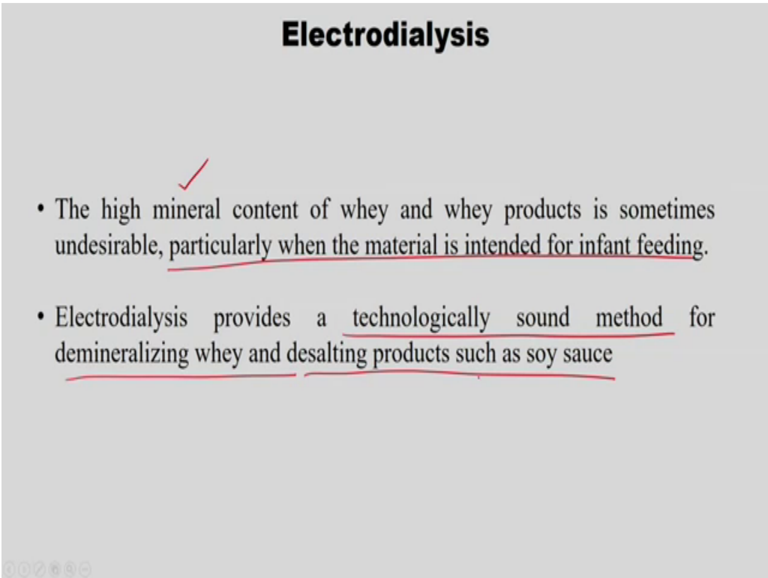

And the high mineral content of whey and whey products is sometimes undesirable particularly when material is intended for infant feeding. So that means, the high mineral content in the whey or whey products, so there also electro dialysis provides technologically sound method for demineralizing whey and desalting products such as soy sauce. So these two applications also electro dialysis is being used.

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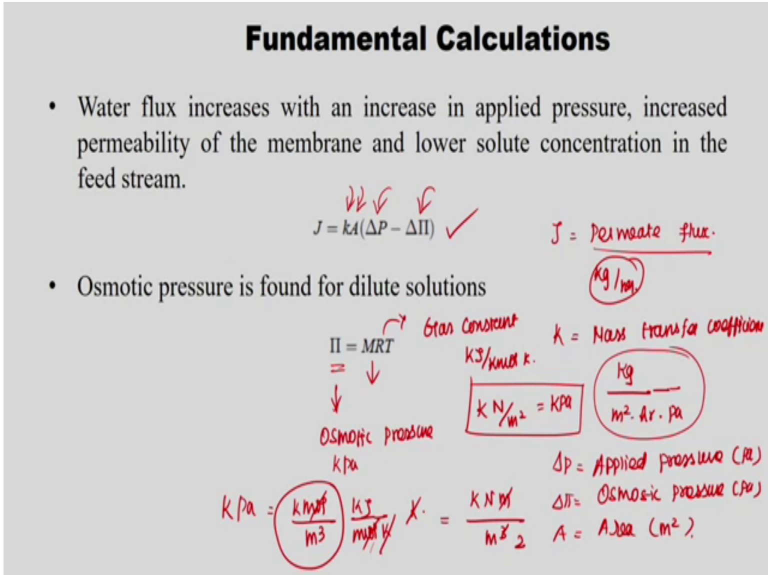

So in the fundamental calculation wise, we supposed to calculate the water flux, right. So for that the formula being used is J equal to kA Del P minus Del Pi, so, the J is nothing but a permeate flux, permeate flux so which is kg per hour, okay. So where K is nothing but the mass transfer coefficient, mass transfer coefficient, so which is in the unit of kg per meter square, per hour and Pasacl, okay.

So Del P and Del A in Pascal, so Del P is nothing but applied pressure, applied pressure, so which is also in Pascal. So Del Pi is nothing but your osmotic pressure, osmotic pressure which is also in Pascal. So A is nothing but a area, which is in meter square, okay. So this is Pi which is nothing but a osmotic pressure. So your M is nothing but in terms of concentration.

So this is your Pi is nothing but osmotic pressure, osmotic pressure, osmotic pressure, so which is in Pascal, okay. So your R is nothing but, so which is in Pascal, your R is nothing but a gas constant which is nothing but kilo joules per kilo mole Kelvin, right. So kilo joules per kilo mole per Kelvin, so your T is in Kelvin, T is nothing but a temperature. So this is nothing but kilo mole per meter cube.

So this is nothing but the Million, right. So that is nothing but a concentration, M is nothing but a concentration, so the kilo mole, kilo mole gets cancel, Kelvin, Kelvin gets cancel, you will get kilo joule is nothing but Newton meter, so this is nothing but meter cube, so which is nothing but meter square. So it is nothing but kilo Newton per meter square, so we call it as a KPa, okay. So your whatever the osmotic pressure you calculate which will be in KPa, right.

So kilo Pascal, so your M is nothing but a concentration here, so that is nothing but moles per meter cube, kilo moles per meter cube and your R is nothing but a gas constant, kilo joules per kilo mole Kelvin, the T is nothing but Kelvin, Kelvin, Kelvin get canceled, kilo mole, kilo mole get cancel, so kilo joules per meter cube, so kilo Newton meter, joule is nothing but a Newton meter, so kilo Newton per meter square which is in KPa. So this is the way you can calculate osmotic pressure Pi is nothing but MRT, M is concentration, R is gas constant, T is temperature.

So after calculating the osmotic pressure difference you can go back and substitute in the Flexi equation. So this is automatic pressure, this is applied pressure, K is nothing but a mass transfer coefficient, A is the area, so you will get your permeate flux in terms of kg per hour here, okay. So if you apply your mass transfer coefficient in terms of kg meter square hour Pascal. So if possible, we will do one or two problems in next class.

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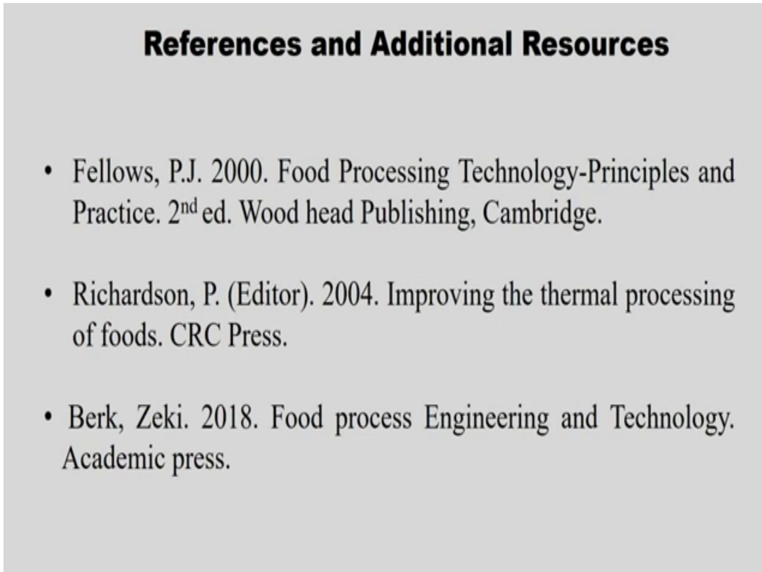

And these are all the resources and additional references what I have used in this lecture. Thank you.