Membrane Technology
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Lectute-17
Advantages of RO, Fouling, RO applications, Pressure Retarded Osmosis

Good morning students, today is lecture 17 of the module 6.

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Module	Module name	Lecture	Title of lecture
06	Reverse Osmosis and Nanofiltration	17	High pressure and Low pressure RO, Advantages of RO
			RO Applications, Fouling, Forward osmosis
			Forward osmosis and Pressure Retarded Osmosis

So in todays lecture will cover High pressure and Low pressure RO, Advantages of RO, then, different applications of the reverse osmosis process, what are the fouling, that is being encountered in RO and how to overcome those, then we will try to learn what is pressure retarded osmosis and the various applications of forward osmosis.

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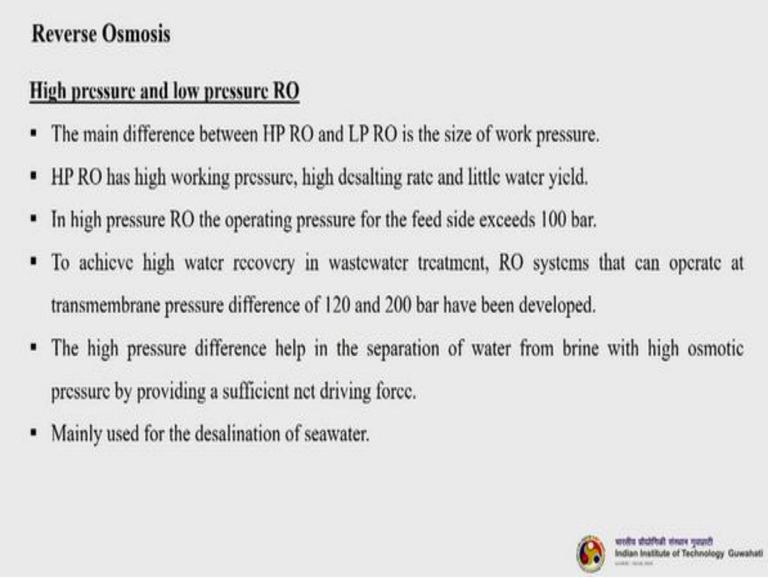

So as the name indicates, high pressure and low pressure RO. It is quite clear that they are differentiated based on the size of their work pressure. So, that means, what is the pressure that is being applied to achieve this targets a separation that actually differentiates between this high pressure and low pressure RO. So high pressure RO has high working pressure high desalting rate and little water yield.

So, in high pressure RO the operating pressure for the feed side exceeds 100 bar. To achieve high water recovery in wastewater treatment, RO systems that can operate at transmembrane pressure difference of 120 to 200 bar have been developed. Now, high pressure difference help in the separation of water from brine with high osmotic pressure by providing a sufficient net driving force. So, high pressure RO is basically used for mainly for the desalination of seawater.

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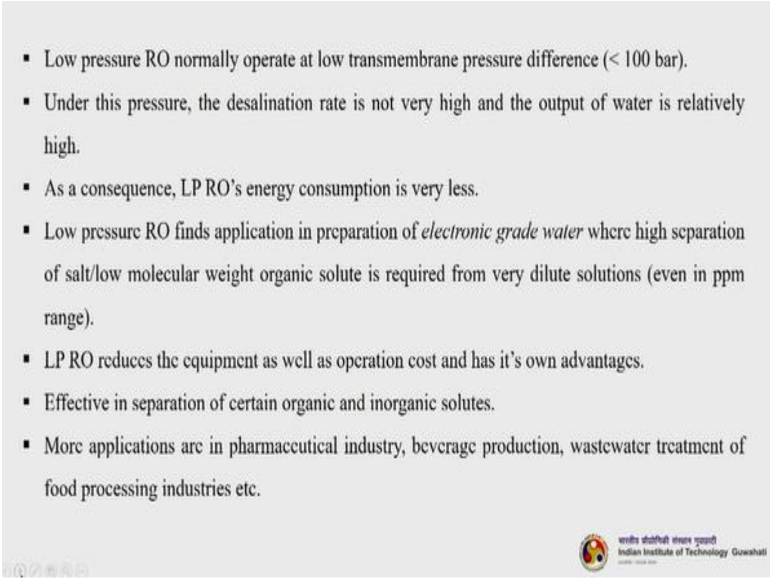

Now, in low pressure RO normally it operates at low transmembrane pressure difference is less than 100 bar. So under this pressure, the desalination rate is not very high however the output of water is actually large or high you can say. So, as a consequence, low pressure RO's energy consumption is very less. Low pressure RO finds application in preparation of electronic grade water.

Which is used in electronics industries actually where high separation of salt and low molecular weight organic solute is required from very dilute solutions, even in ppm ranges? Now, low pressure RO reduces the equipment as well as operation cost and has it is own advantages. Now they are extremely effective in separation of certain organic and inorganic solutes.

More applications of low pressure RO are found in pharmaceutical industry, beverage production, wastewater treatment of food processing industries, etc.

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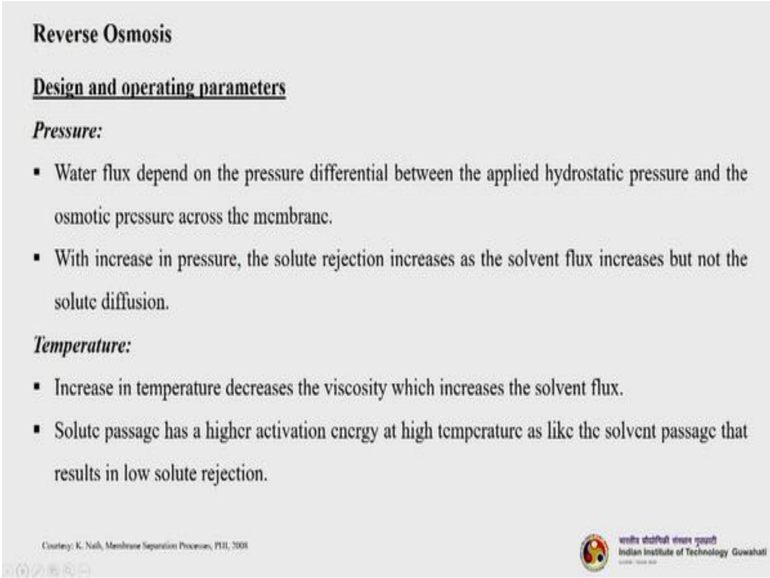

Now, let us understand the different design and operating parameters; that affect the overall performance of the reverse osmosis systems. The first one is pressure; the pressure is the most important parameter. So we know that, water flux depends upon pressure differential between the applied hydrostatic pressure and the osmotic pressure across the membrane. So, with increase in pressure, the solute rejection increases as the solvent flux increases but not a solute diffusion.

So, next is temperature; increase in temperature decreases the viscosity which increases the solvent flux. Solute passage has higher activation energy at high temperature as like the solvent passage that results in low solute rejection.

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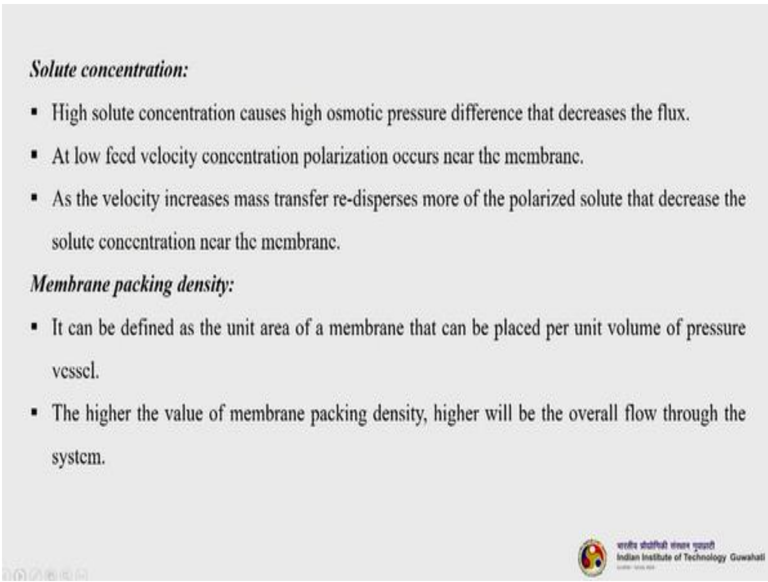

Apart from pressure and temperature other parameters which affect the performance of RO are solute concentration, so high solute concentration causes high osmotic pressure difference that decreases the flux. So at a low feed velocity concentration polarization occurs near the membrane and as the velocity increases mass transfer re-disperses more of the polarized solute that decreases the solute concentration near the membrane.

So, that means velocity increases the concentration polarization build up slowly, slowly gradually and your increase in velocity of the feed, so this feed actually passes away at the low concentration polarization build up as already taken place, so there by decreasing the solute concentrations near the surface of the membrane. So the next parameter is membrane packing density; this is the most important parameter.

So you can define membrane packing density as the unit area of the membrane that can be placed per unit volume of pressure vessel. The higher value of the membrane packing density, higher will be the overall flow through the system.

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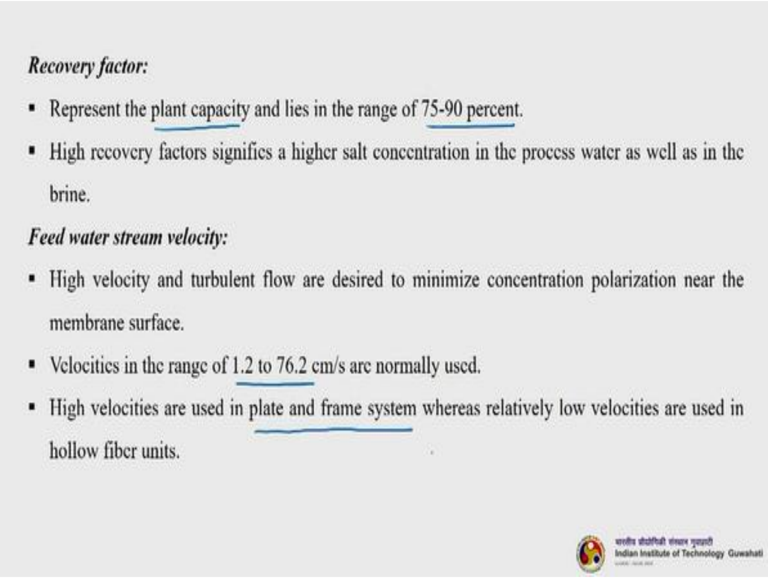

So, the next one is recovery factor; it represents the plant capacity and lies in the range of 75-90 % usualy. So higher recovery factor signifies a higher salt concentration in the process water as well as in the brine and then the next parameter is feed water stream velocity; high velocity and turbulent flow are desired to minimize concentration polarization near the membrane surface, which I told in the earlier slide. Velocities in the range of 1.2 to 76.5 cm/s are normally used.

High velocities are used in plate and frame system whereas relatively low velocities are used in hollow fiber systems.

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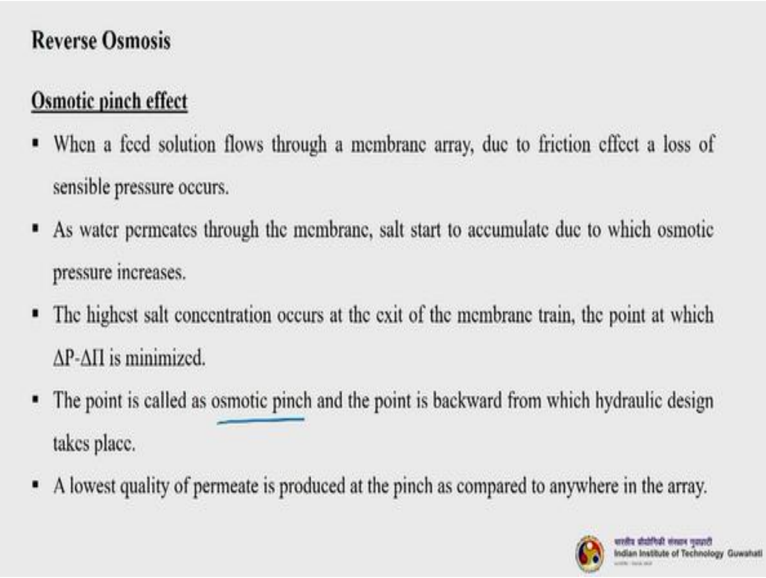

Now let us understand what is Osmotic pinch effect? This is important for forward osmosis and reverse osmosis pressure system. So when a feed solution flows through a membrane array, due to friction effect a loss of sensible pressure occurs so due to friction actually some pressure drop is occurring as water permeates through the membrane, salt start to accumulate due to an osmotic pressure increases.

The highest salt concentration occurs at the exit of membrane train, the point at which delta P - delta Pi is minimized. So, the point is called as osmotic pinch and the point is backward from which hydraulic design takes place. A lowest quality of permeate is produced at the pinch as compared to anywhere in the array.

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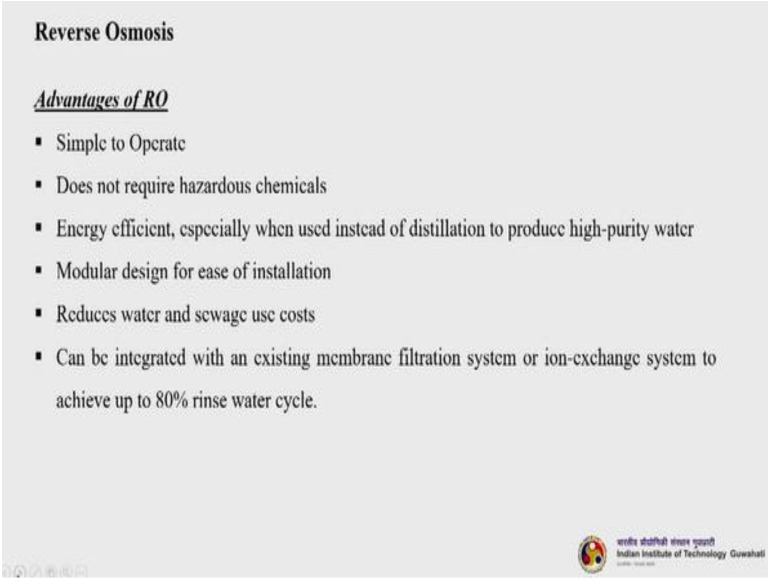

So, let us understand what are the advantages of RO? So, as you know that RO systems are little simple to operate, compared to other systems, membrane processes. That does not require hazardous chemicals, their energy efficient, especially when used instead of distillation to produce high purity water, modular design for ease of installation, reduces water and sewage use costs.

It can be integrated within existing per membrane filtration system or ion-exchange system to achieve up to 80% rinse water cycle.

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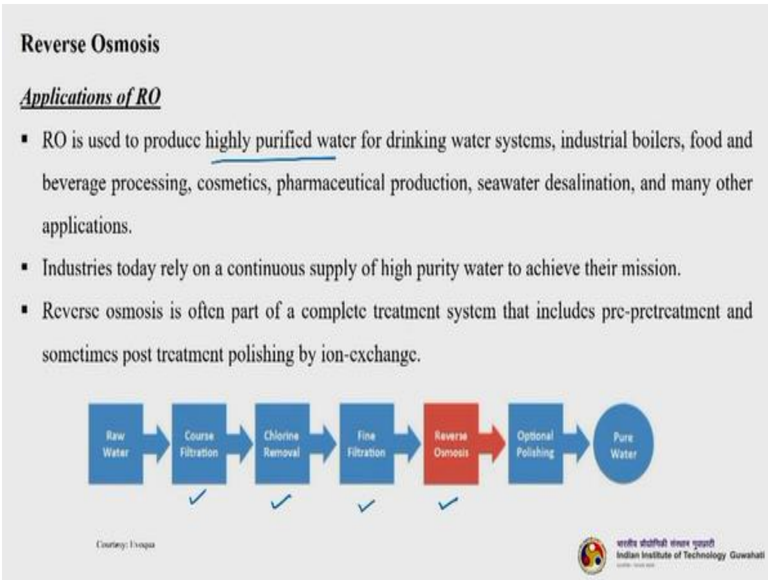

So now let us try to understand and learn different types of applications of RO; we will discuss two different applications. So there are many. So RO is used to produce highly purified water for drinking water systems, Okay? Industrial boilers water, food and beverage processing industries, cosmetics, pharmaceutical production, seawater desalination, and many other applications.

So, today, industries rely on a continuous supply of high purity water to achieve their mission. Reverse osmosis is often part of the complete treatment system that includes pre-treatment and sometimes post-treatment by ion-exchanging. You can see one schematic representation here, the raw water is how actually the water is getting purified. So water is initially filtered using the course filtration system.

So they remove different types of suspended materials, grease and oils all these things. Then it goes to another process, this one tank, where the chlorine is being removed, okay because chlorine presence is very bad for the most of the membranes. So chlorine has to be removed. Okay, so once that chlorine is removed and then it goes for fine filters, okay to remove other tidies and other things, Okay?

Then when then next is, it goes to the RO system. So, once it comes out from the RO system. So, sometimes it requested there are certain ions which has come out, or being present so that needs to further policing using usually ion exchange, otherwise RO itself produces very high quality of pure water, it depends upon what is the intended application basically.

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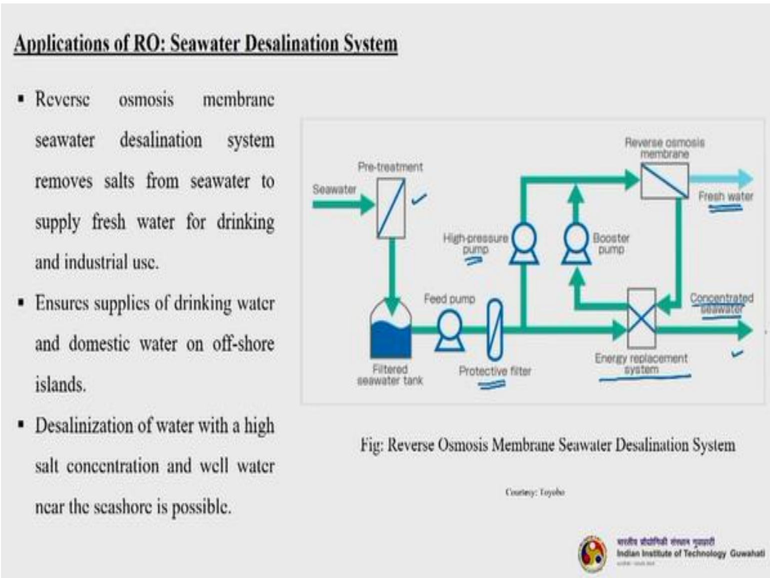

Let us see this particular application; this is sea water desalination which is one of the most important and widely adapted RO applications. So, RO membrane seawater desalination system removes salt from seawater to supply fresh water for drinking and industrial uses. So ensures supplies of drinking water and domestic water on off-shore islands. Desalination of water with a high salt concentration and well water near the seashore is also possible.

So this is a classic example of a reverse osmosis desalination system. This is proposed by a company called Toyobo, which is a leading manufacturer of the RO systems. So you can see what is happening in this particular scheme, so seawater is coming and there is some pre-treatment is occurring here, Okay? So this pre-treatment as I told it is usually remove here suspended particules and all, and then it goes to a tank so filter seawater physically.

So then you use a feed pump Okay? To pump it to the RO systems, so in between we have different types of protective filter to remove again. So, separate at all suspend materials is there are, large molecular weight compounds out there it will remove it, then again if you use another high pressure pump to feed it to the RO system. So this is your RO system, right? So here actually what is happening?

So this high pressure pump is required to supply the delta p that is required to do the RO. So, when the RO membrane will desalinate this one seawater and you get fresh water as permeated. So whatever that detector is there, so that is nothing but concentrated seawater. So that again comes to something called an energy replacement system, where energy is virtually many times, energy is required to cover it. Okay? Using certain specialist systems, right?

So part of that can again be recycled back to the RO system because kindly note that this is a continuous system. So you have to maintain the feed the amount of the feed you have feeding actually that needs to maintain and the concentration also if you maintain also then if you can run the system for more time, Okay? And you finally get your concentrative seawater there are here, it can be rejected.

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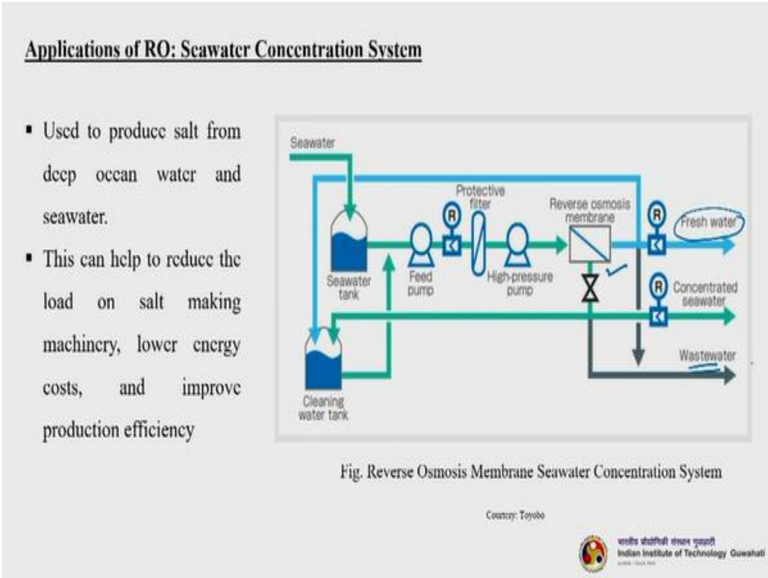

The next application is actually again taken from Toyobo. So, this is sea water concentration system, this is used to produce actually salt, okay? So this particular process is producing salt actually from deep ocean water and seawater. So this can help to reduce the load on salt making machinery, low energy cost and improve production efficiency. You can see this, sea water is coming here, Okay? And is being feed to a RO system, this is RO system here, Okay?

So whatever freshwater you are getting Okay? So that is basically, permeates side and whatever you are getting here is the wastewater, Okay? So that is basically the concentrator side, right? So this concentrated side actually you have been using basically to produce salt. So what is happening in this process is this, this RO is reaching here concentrated, this one seawater to more concentrated water, Okay?

So that basically the aim is to increase the salt concentration in the water, so that it can easily be resulted into that salt. So more salt can be produced from the seawater or concentrated seawater rather than using the usual sea water, which is usually at a 30000 to 35,000 ppm concentration. So if you can make it to more than 1 lakh even more than that ppm then the production of salt, the rate of production is very higher basically.

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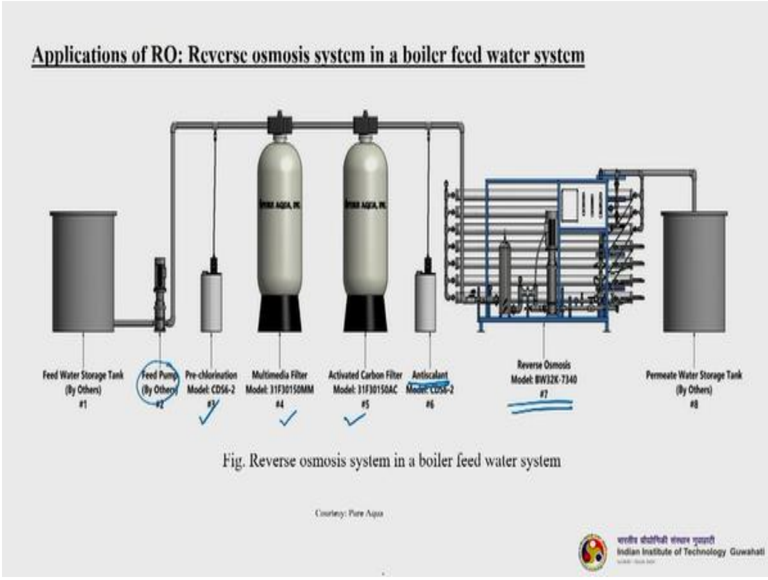

So, this is another classic example of RO in a boiler feed water system. So, here the RO is being RO system is being used to produce boiler feed water, right? So you can see this feed water storage tank is there from where it is feed pump is there, Okay? So this pump is feeding water. First, it goes to the deep chlorination unit here, so when the deep chlorination is happening, then it goes to different types of media filters.

Firstly, there is a multimedia filter is there, it will remove the suspended solids and other things, then it goes to activated carbon filter it will remove any other ions which are not required and other low molecular weight compounds also, then you can add antiscalent here and here, right? So which will reduce the scaling permission inside the RO system, then finally it goes to the RO system okay?

This is taken from Pure Aqua a company again leading manufacturer of RO systems. Then you get a permeate water storage tank, so this is, this goes to the boiler feed, so please remember this. This also produces very good quality of water. Though you cannot directly use it as portable water you may need some polishing technique, but boiler water the main thing is that it should be removed of any such items which pumps scales.

Otherwise the boilers will get, will have a lot of scale operation, so there operations will become difficult.

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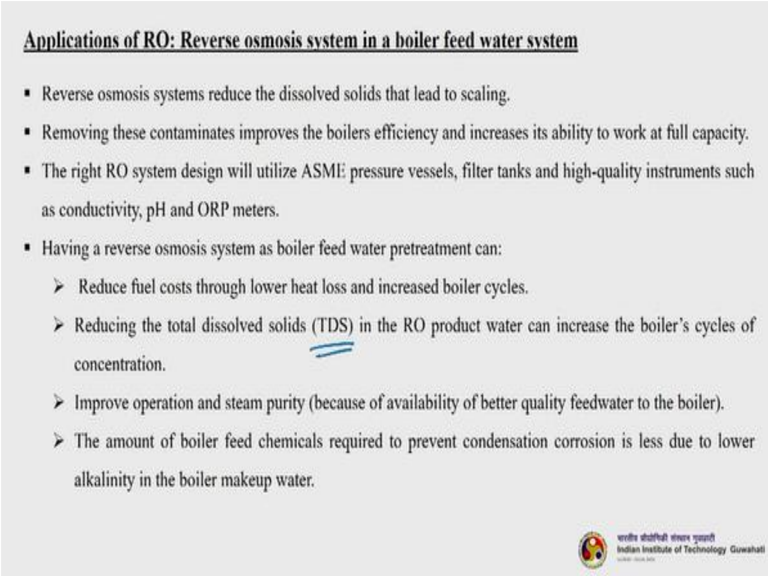

So, the reverse osmosis system reduces the dissolved solids that lead to scaling, as I was telling, so the main use of RO here is to remove the scale formation solids. So removing these contaminates to improve the boilers efficiency and increase its ability to work at full capacity. That right RO system design will utilize the ASME pressure vessels, filter tanks and high quality instruments such as conductivity, pH and ORP meters.

Having a RO system as boiler feed water pre-treatment can; reduce fuel costs through lower heat losses and increase boiler cycles, reducing the total dissolved solids, this is another very important thing in the RO product water can increase the boiler cycle of concentration and as much as TDS and anti-scale formation compounds we are removing. So you are basically increasing the life of the boiler.

So improve operation and steam purity, because of availability of better quality feed water to the boiler. So the quality of steam becomes very good actually. The amount of boiler feed chemicals required to prevent condensation corrosion is less due to lower alkalinity in the boiler makeup water.

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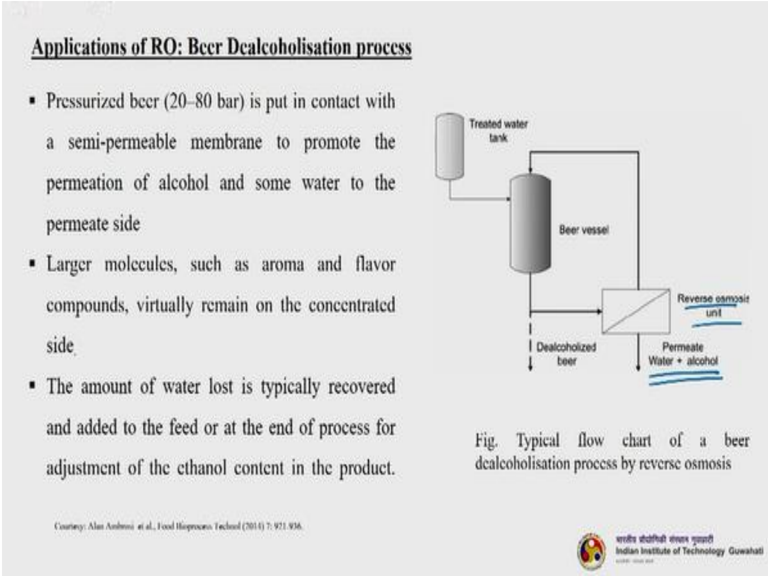

So another example, which is also very famous in process industries, is the Beer Dealcoholisation process. So what is being done is that in nowadays in many of the Western countries people are not at all liking beer as it becomes with little higher alcohol present they need or preferring actually less amount of alcohol in the beer, okay? But however at the same time the fragrance or taste of the beer needs to be maintained.

So that is another thing actually we are going to so that we taking care of when we are going to dealcoholisation, so a pressurized beer 20 to 80 bar. So that is put in contact with a semi-permeable membrane to promote the permission of alcohol and some water to the permeate side. So that means here the permeate sides, some water and alcohol is getting comes, water is coming along with that, I will call it coming.

But one of the disadvantages in that system this particular system is actually. So, it becomes a costly process RO system and you need high pressure, so that is one of the most important things that, has to be taken care when you calculate overall process cost. So larger molecules, such as aroma and flavor compounds, they virtually remain in the concentrated side. So, the amount of water lost is typically recovered and added to the feed or at the end of the process for adjustment of the ethanol content in the product.

So how much actually alcohol present is required, so you can prefix that, accordingly you can go to one step process, two step process or remain multi step process to achieve that, okay? There by retaining the flavor and the taste of the beer.

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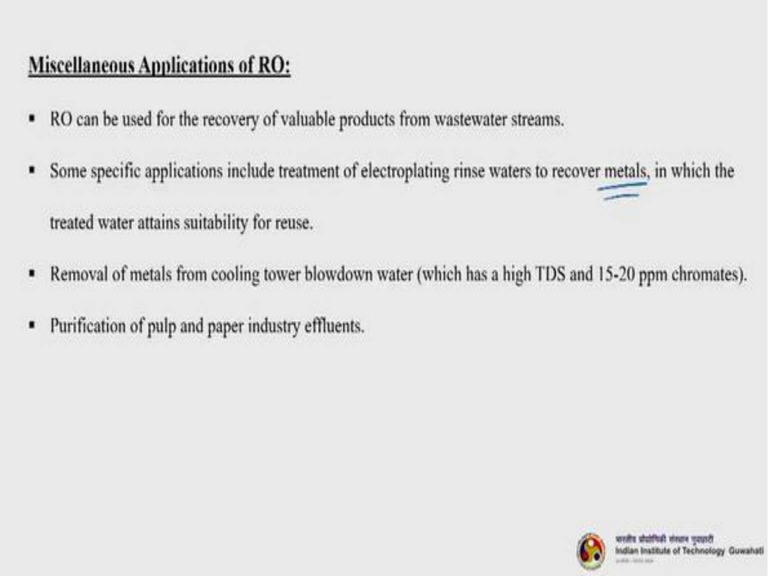

So there are certain a miscellaneous application of RO also exists, so RO can be used for recovery of valuable products from wastewater streams. Some specific applications include treatment of electroplating rinse waters to recover heavy metals, Okay? In which the treated water attains suitability for reuse. So removal of metals from cooling tower blow down water, which has a high TDS and 15 to 20 ppm chromates.

Purification of pulp and paper industry effluents. So now a days as you know that most of the process industries water or you can call it waste water but that definitely content some of the things. So, either metals, heavy metals, then your different types of ions, or even some organic compounds. So it seems the amount of free water that is accessible to most of the industries is getting decrease day by day.

So it is the need of the hour to treat the water bottle whatever it is coming out from the process to. So, those the idea is that if you treat it. Then you can get a better quality of water, so the water can be recycled and reuse. So we need to have more amount of fresh water which eventually decreases. So that is actually the basic aim of most of the industries now days.

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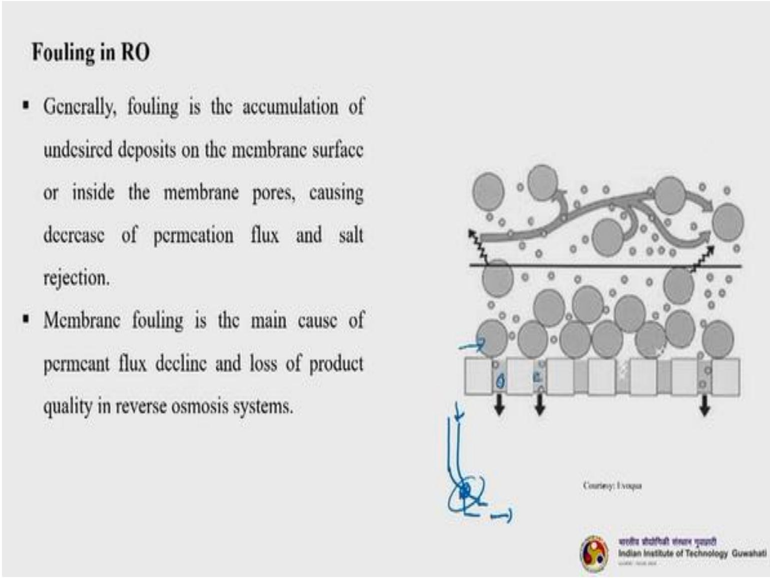

So let us now understand the fouling, we have discuss fouling during microfiltration and all. So the same process actually how the fouling occurs, so initial the concentration of polarization will occurs, so that means the build up of this solid molecule. As you can see, different, different size molecules are getting deposited on the surface of the membrane some solids will block the pore of them, you can see this. Okay? They are blocking it partially here, Okay?

Some solutes which are smaller in size of that of pore mouth, it eventually get inside the pores and if this passages constitute, so if you remember, this is something like this is constitute, once again, it opens up. So, they will get deposited in this particular area, even if the pore is open from both sides, and now this becomes a dead end. So, this particular word now becomes fouled, Okay?

So membrane fouling is the main cause of permanent flux decline, and the loss of product quality in RO system, not only RO in all systems, even whether it is microfilters or macrofilters the permeate plus declares basically due to the fouling of the concentration polarization build up.

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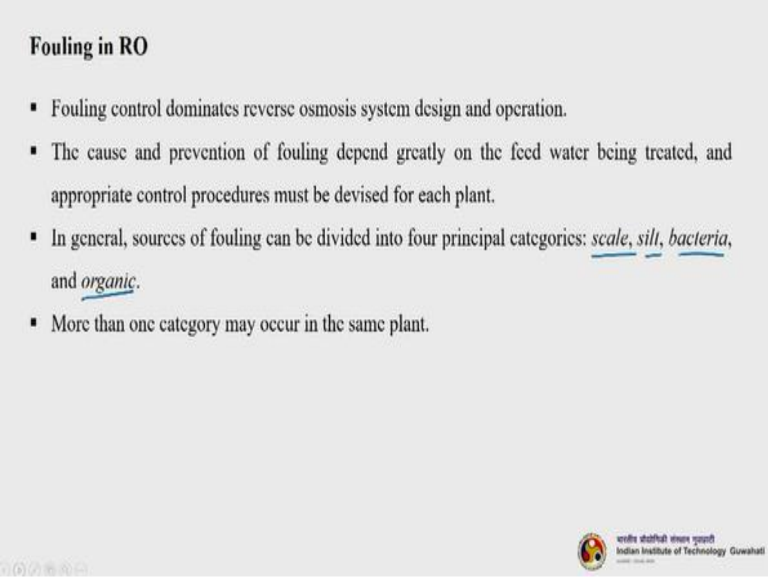

So, fouling control dominates RO system designed and operation because most of the RO system they operate continuously, especially the desalination thing, the cause and prevention of fouling depend greatly on the feed water being treated and appropriate control procedures must be a devised for each plant. In general sources of fouling can be divided into four principle categories.

So, they are scale, silt, bacteria and organic compounds, so more than one category may occur in the same plant. So that is also possible especially when you are talking about the desalination of seawater, the sea water contains so many compounds, Okay? It has the scale forming compounds, it has silt, it has bacteria, it has organic compounds also, Okay?

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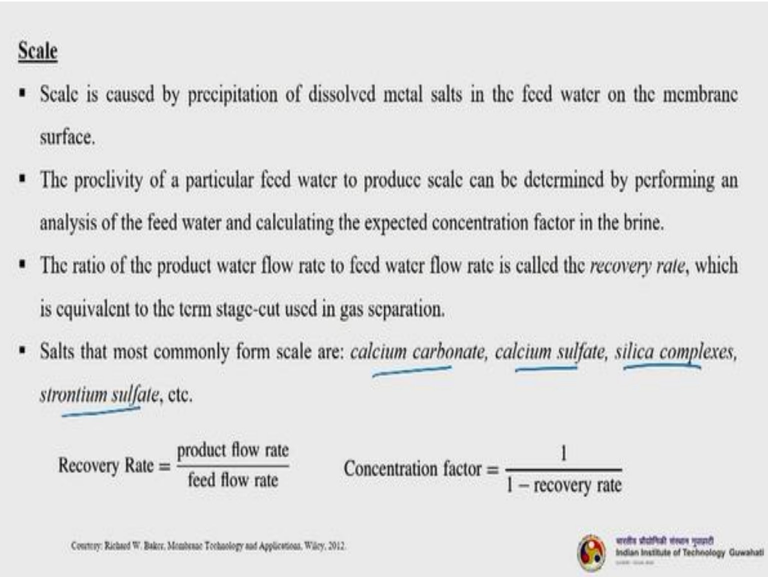

So, let us see one by one this different types of components these are responsible for the fouling. First one is the scale, scale is caused by precipitation of dissolved metal salts in the feed water on the membrane surfaces. So the proclivity of particular feed water to produce scale can be determined by performing an analysis of the feed water and calculating the expected concentration factor in the brine.

So we need to calculate the recovery rate as well as concentration factor to understand how much scaling can be possible using particular seawater or you can call it feed water basically. The ratio of the product water flow rate to feed water flow rate is called recovery rate, which is equivalent to the term stage-cut used in gas separation membrane. S o salts that mostly commonly form scale are; calcium carbonate, calcium sulphate, silica complexes, strontium sulphate, etc.

So your recovery rate is given by product flow rate by feed flow rate and concentration factor is one minus one over one minus recovery rate.

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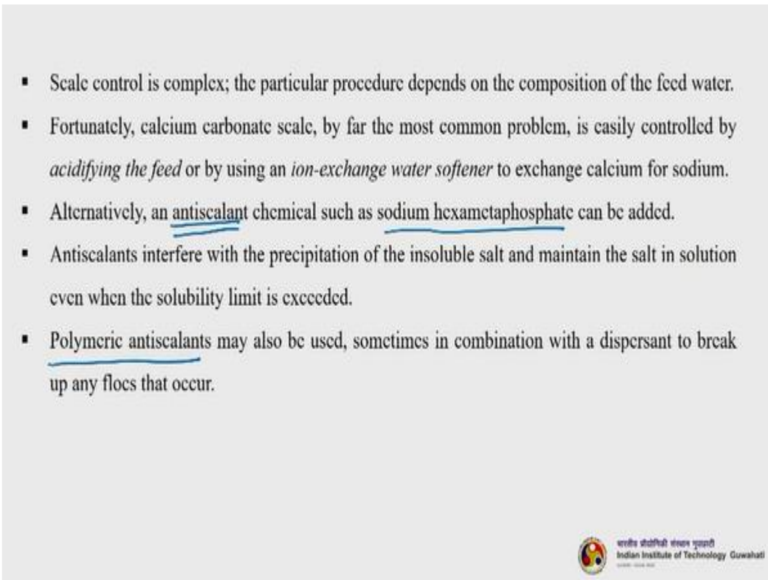

Scale control is complex; the particular procedure depends on the composition of the feed water system. The feed water composition varies so that is why scale controlling is complex phenomena. Fortunately, calcium carbonate scale, by far the most common problem, is controlled by acidifying the feed or by using an ion-exchange water softener to exchange calcium for sodium.

Alternatively, an antiscalant chemical such as sodium hexametaphosphate can be added. So this will help in reducing the scale formation it will bound the scale forming compounds and those can be removed or recovered from the feed water. So antiscalants interfere with the precipitation of the insoluble salt and maintain the salt in solution even when the solubility limit is exceeded.

So polymeric antiscalants are also now a days available, sometimes in combination with a dispersant to break up any flocs that occurs in the feed water.

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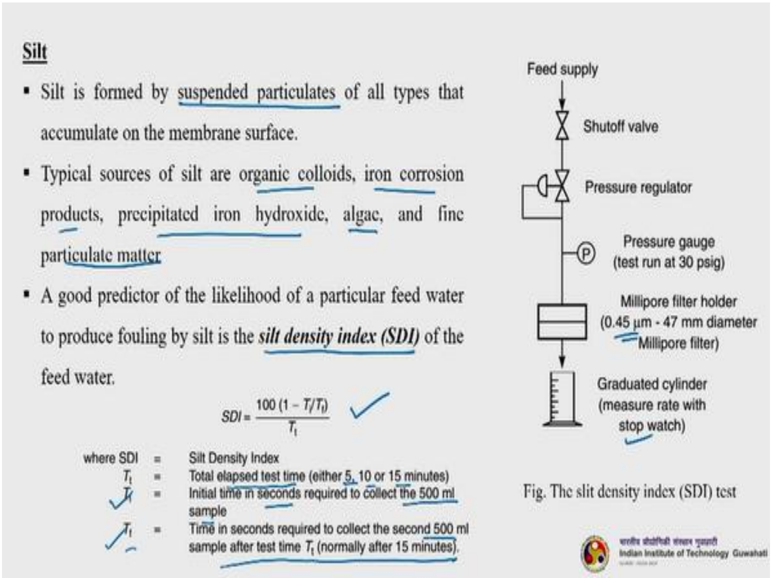

So the next is silt, silt is formed by suspended particulates of all types that accumulate on the membrane surface. So typical source of silt are organic colloids, iron corrosion products, precipitated iron hydroxide, algae and fine particulate matter. So a good predictor of the likelihood of a particular feed water to produce fouling by silt is the silt density index, it is called SDI of the feed water.

Now, you can see this figure, this is silt density index is how it is being conducted actually see this particular equation. This equation is used to calculate the SDI, the silt density index. So SDI equals to 100 in bracket one minus Ti by Tf divided by Tt, what is Tt, Tt is the total elapsed test time, either 5, 10 or 15 minutes this you can fix actually, then Ti is the initial time in seconds required to collect the 500ml of the sample, Tf is time in second required to collect the second 500 ml of the sample after the test time Tt normally after 15 minutes.

So what is the meaning of this, so you please, can i have a look in this particular figure, You see that usually 0.45 micrometre filter, not necessarily Millipore filter. It can be a millipore filter also being utilized, Okay? And you are pushing water through this sea water right? Anyone measure this volume here. So how do you measure? So the first is that the Ti is the first, you start the time and see, that was count the time.

Till you collect 500 ml of the initial sample per minute, you are collecting it per minute, right? So whatever time it takes to collect the 500 ml of the first permeate sample is called Ti right? Now what happen the second thing is that, again, you give it some time then again you start collecting the 500 ml of again, the second per minute or 500 ml. Okay. After 15 minutes and then time required collecting the 500 ml per minutes is given by Ti.

And Tt is the total elapsed time, it can be either 5, 10 or 15 minutes depending upon what procedure you are adopting.

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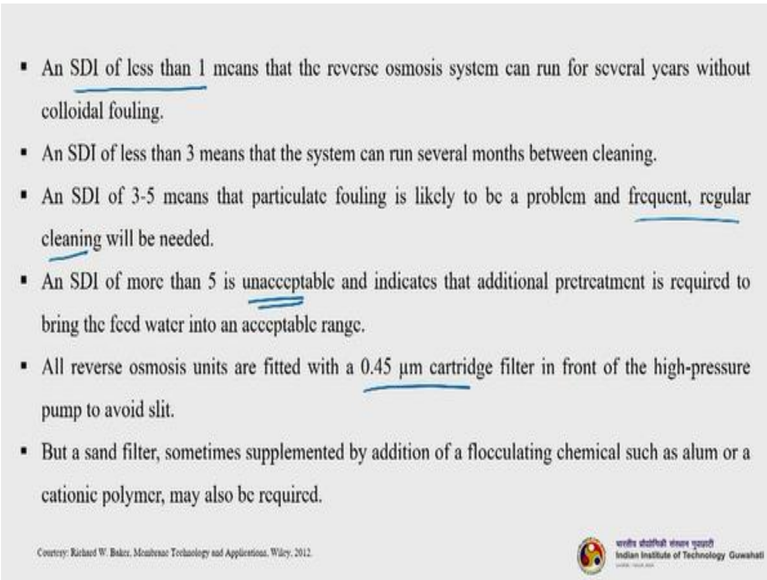

So in SDI of less than 1 means the reverse osmosis system can run for several years without colloidal fouling. So an SDI of less than 1 is usually better, and recommended. Okay, so the SDI less than 3 minutes. The system can run several months between cleaning and SDI of 3-5 minutes that particular fouling is likely to be a problem and frequent and regular cleaning will be needed.

So now you understand what is the importance of a SDI basically and how do you measure it, and An SDI of more than 5 is unacceptable at all and indicates that additional pre-treatment is required to bring the feed water into an acceptable range. So it is understood that you cannot simplified the seawater or any such feed water to OR system without understanding what is its composition that will foul the membrane and you will get nothing out of the RO.

So all the RO units are fitted with the 0.45 micrometre cartridge filter in front of the high pressure pump to avoid slit and this is slit actually. But a sand filter, sometimes supplemented by addition of a flocculating chemical such as alum or a cationic polymer may also be required.

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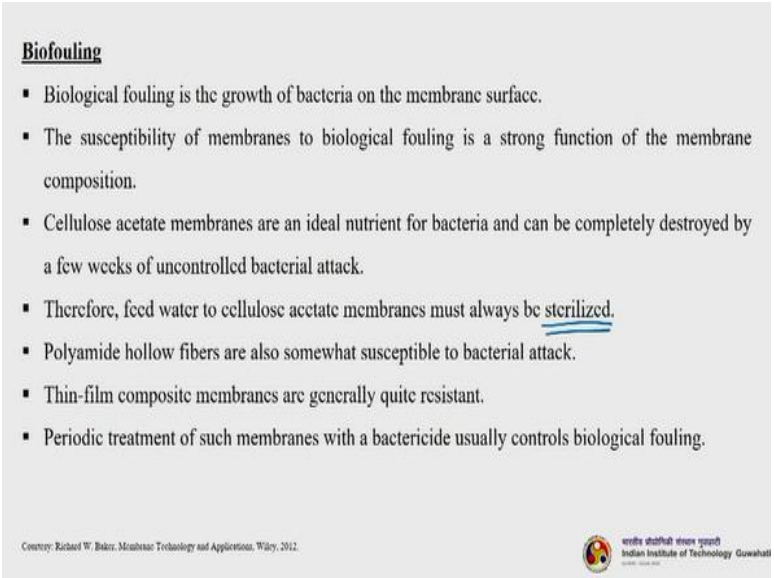

So next category of the scale formation of fouling problem is due to the biofouling, Okay? Biological components, biological fouling in the growth of bacteria on the membrane surface, the susceptibility of membranes to biological fouling is a strong function of the membrane composition. Cellulose acetate membranes are an ideal nutrient for bacteria, and can be completely destroyed by a few weeks of uncontrolled bacterial attack.

We have discussed this thing when you discuss the membrane material characteristic pinches properties, so that the time we have discussed that cellulose acetate, or cellulose derivatives are not at all good for fouling tendencies because the bacteria which will deposit on the surface of the membrane, they will you try to use the cellulose as their subject for their own growth. Therefore, feed water to cellulose acetate membranes must always be sterilized.

If you are using cellulose acetate membrane, but again you are adding an extra cost to the entire process. So polyamide hollow fibers are also somewhat susceptible to bacterial attack, but that less broad with comparison to the cellulose acetate membrane. Thin film composite membrane generally quite resistant because anyway you have a asymmetric structure and periodic treatment of such membranes with a bactericide usually controls biological fouling.

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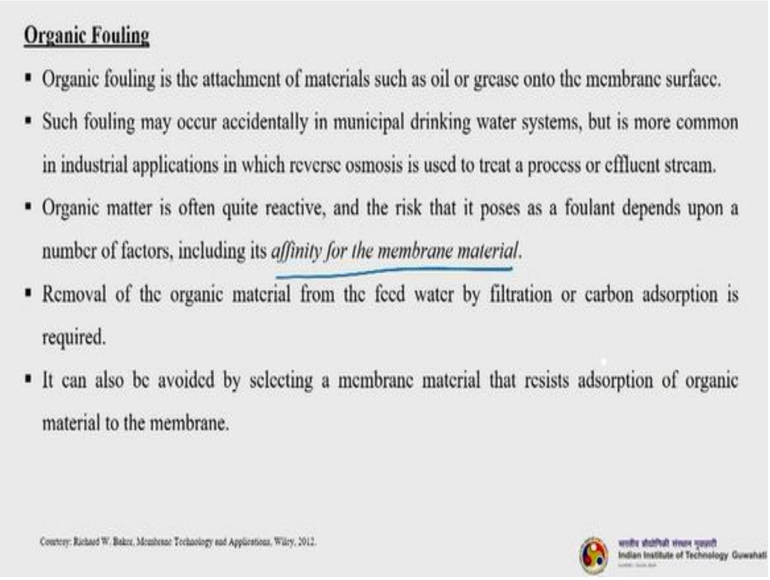

So, organic fouling is the attachment of materials such as oil or grease onto the membrane surface. Such fouling may occur accidentally in municipal drinking water systems, but it is more common in industrial applications which reverse osmosis is used to treat a process or effluent stream. They are more common in refinaries, okay? Oil manufacturing companies, whether it is eat or eatable or oil for cooking process or it this one crude oil processing industry such as refineries.

Organic matter is often quite reactive and the risk that it poses as a foulant depends upon a number of factors, including its affinity for the membrane material. One of the most important thing about organic compounds is what is their affinity towards membrane material, okay? So affinity is depends upon the type of membrane material and of course the organic compounds properties.

So the removal of the organic material from the feed water by filtration or carbon adsorption is required. It can also be avoided by selecting a membrane material that resists adsorption of organic material to the membrane.

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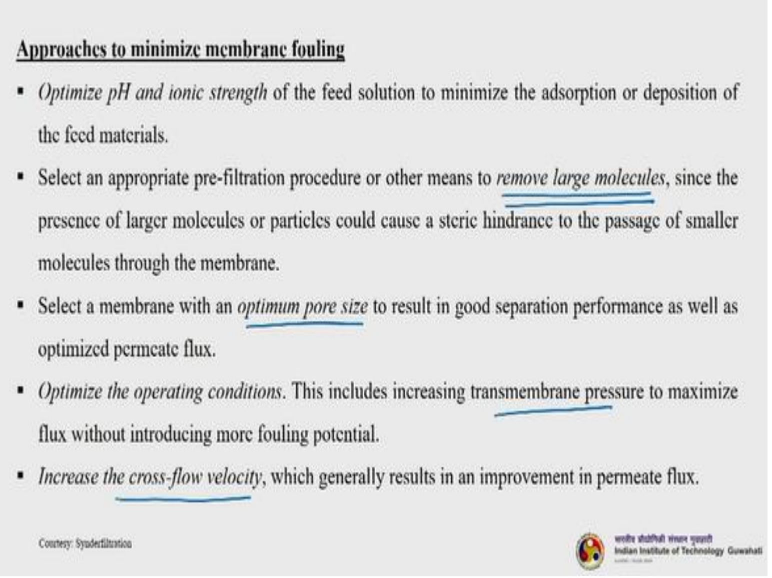

So now let us understand how to minimize the membrane fouling. So, you can do it by various methodologies, or techniques. So the first one is, optimize the pH and ionic strength of the feed solution to minimize the adsorption or deposition of the feed materials. So you can play with the pH, you can easily optimize the pH by adding acid or alkaline required, so that the adsorption or deposition of the fouling from the surface of the membrane will become less.

And select an appropriate pre filtration procedure, so as to remove the large molecules. So it is always better to say you have seen in the two schematic diagrams that we have seen which were proposed by these toyobo companies of the desalination as well as the concentration of the seawater. In both we have seen that there are three filters in between. So, the role of desalination filter is to mostly through remove the large molecule level compounds.

Since the presence of larger molecules or particles could cause a steric hindrance to the passage of smaller molecules through that membrane. Select a membrane with optimum pore size to result in good separation performance as well as optimized permeate flux. Then optimize the process conditions operating conditions. So this includes that increasing transmembrane pressure to maximize the flux without introducing more fouling potential.

Increase the cross-flow velocity, when that cross flow velocity will be higher, it will wash away most of the deposition on the surface of the membrane, thereby reducing the concept of polarization.

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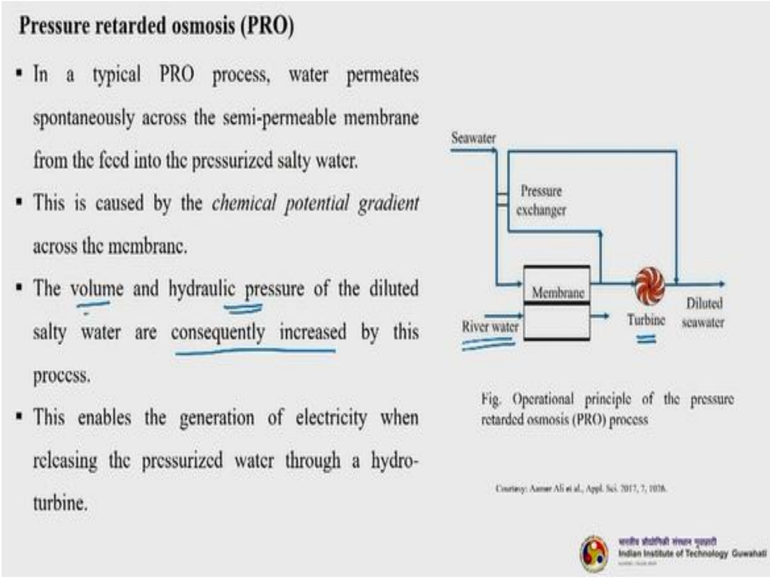

Let us understand what is PRO or pressure retarded osmosis. This is one of the classic example of a membrane system, in which the membrane system itself being used to generate electricity. How it is happen, let us understand and see. So in a typical PRO process, water permeated spontaneously across the semi-permeable membrane from the feed into the pressurized salty water.

You can see how what is happening the river water. The water, which is divided up the salt is being paired to one side of the membrane, and then the other side, and this is RO membrane of course, and in other sides you are feeding the seawater. So the seawater is transport is happening due to the chemical potential gradient across the membrane and the volume and hydraulic pressure of the diluted, salty water are consequently increased by this process.

So the volume is increased, when the hydraulic pressure of the salty water is increased, so this will actually help in generating electricity, because it is being fed to a turbine here you can see this, Okay? This enables the generation of electricity when releasing the pressurized water through a hydroturbine. So, the pressurized water is at very high pressure. So that pressure will be placed to rotate the turbine, water turbine, okay?

When it rotates and you know that that the usual way of generating electricity, Okay?

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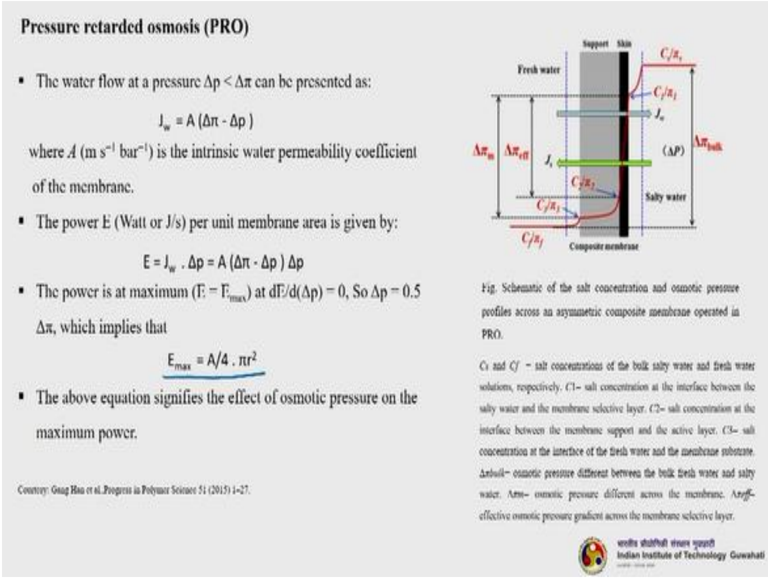

So at least understand the equations involved in the pressure retarded osmosis equations are, so the water flow at a pressure delta p less than the delta Pi can be presented by this equation; Jw equal to A into delta Pi minus delta p, where A is the intrinsic water permeability coefficient of the membrane. The power E, watt per Joules per second per unit membrane area is given by; E equals to Jw into delta p, so that is nothing but A into delta Pi-delta p of delta p.

So, let us understand how you will get a maximum power. So the maximum, the power is maximum E max when at dE by d into delta p equals to 0, so delta p equals to 0.5 into delta Pi, right? Which implies that Emax equals to A by 4 into Pi r squared. The above equation signifies the effect of osmotic pressure on the maximum power, so more osmotic pressure equals to the maximum power.

So this is the schematic of the salt concentration and osmotic pressure profiles across an asymmetric composite membrane operated in PRO system, you can refer it to later.

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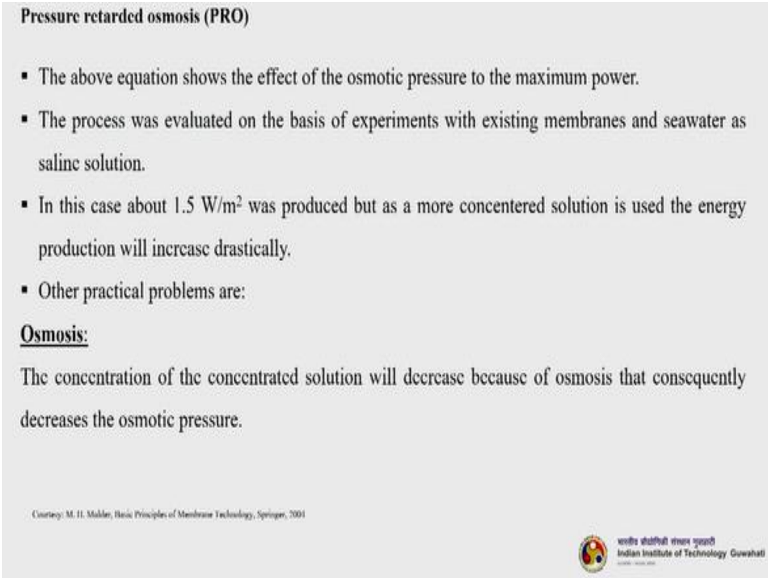

So the above equation shows actually the effective osmotic pressure to the maximum power. The process was evaluated on the basis of experiments with existing membranes and seawater as saline solution. In this case about 1.5 watt per meter squared was produced, but as a more concentrated solution is used the energy production will increase drastically. So other practical problems are associated with the PRO is the osmosis.

Now, the concentration of the concentrated solution will decrease because of osmosis that consequently decreases the osmotic pressure. So eventually when this PRO is going on; there is some osmosis is also happening, so that is creating problem because it will decrease the concentration of the concentrated solution, because we understand that more the concentrated solution more will be the delta Pi more will be the electricity that is being produced.

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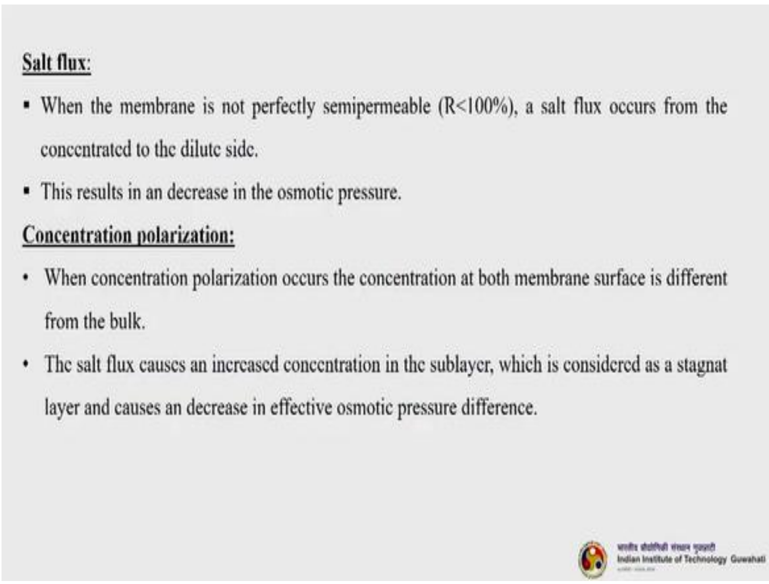

So, another problems are salt flux and concentration polarization; the salt flux is actually the when the membrane is not perfectly semipermeable, that is let us say R is less than 100%, a salt flux occurs. So you know that perfectly semi permeable membranes are very difficult to make, so usually there is a salt flux. However, most of the time we neglect salt flux the Jw which is usually we concentrated zero.

So this results due to the salt flux, there is a decrease in osmotic pressure and when concentration polarization occurs the concentration at both membrane surface is different from the bulk, the salt flux causes an increased concentration in the sublayer, which is considered as a stagnat layer and causes an decrease in effective osmotic pressure difference.

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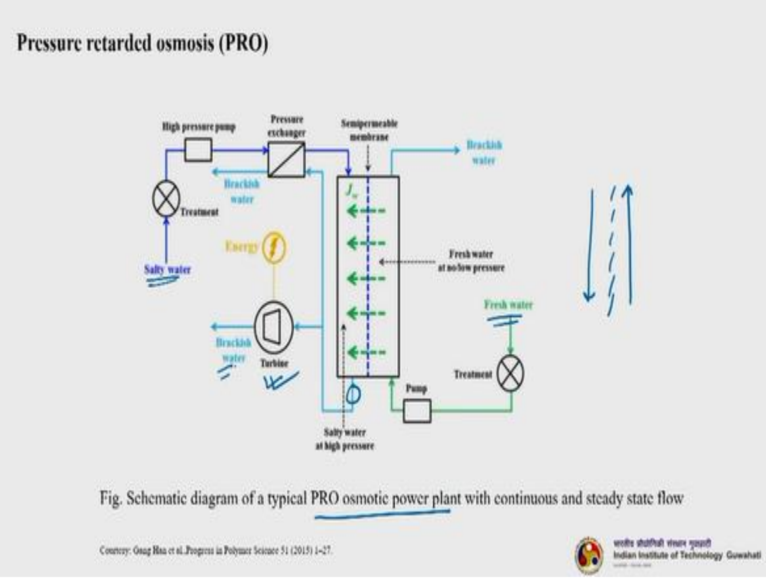

So let us understand a better schematic representation here, entire process of the PRO the pressure retarded osmosis. This is a PRO osmotic power plant with continuous and steady state flow. You can see this saltywater or seawater is being pumped to a pressure exchanger, then from where it coming to the RO system, PRO systems in from one side, and from the other side, fresh water is being pumped here. Okay?

So seawater is coming in this direction, fresh water is coming in this direction and there is a membrane in between Okay? And what is happening the freshwater it lower no pressure is being actually getting pushed to the salty waters side of the concentrator water side, thereby increasing the volume as well as the pressure of the salty water, so whatever the saltwater is coming out here, so they are not at all more concentrated but also a elevated pressure.

So now that elevated pressure at concentrated is being pathway turbine, which will generate electricity, and we get brackish water here, Okay? Now most of this brackish water again filled to this system, Okay? Mix to the feed basically.

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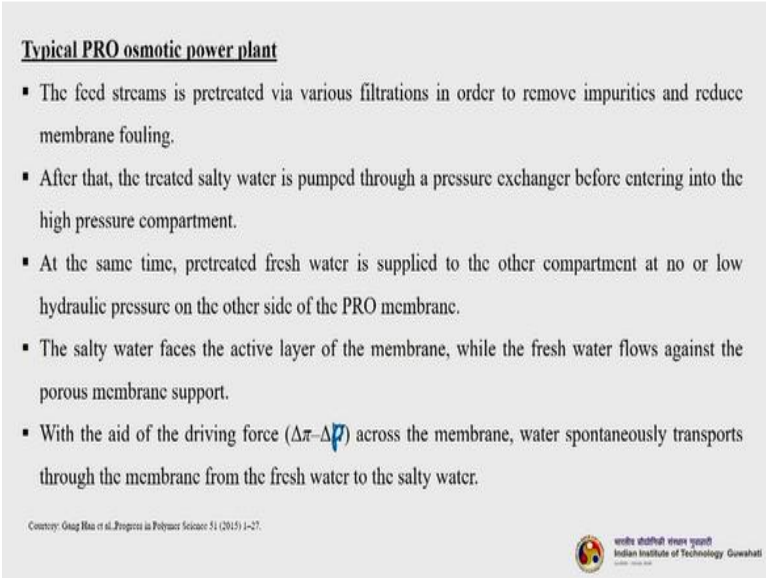

So the feed stream is pre-treated by various filters in order to remove impurities and reduce membrane fouling. So most of the impurities which are present that has to be removed for a continuous operation. After that, the treated salty water is pumped through a pressure exchanger before entering into the high pressure compartment. At the same time, pre-treated fresh water is supplied to the other compartment at no or low hydraulic pressure on the other side of the PRO membrane.

The salty water faces the active layer of the membrane, while the fresh water flows against the porous membrane support. With the aid of the driving force delta Pi minus delta P it will be okay? Across the membrane, water spontaneously transports through the membrane from freshwater to salty water.

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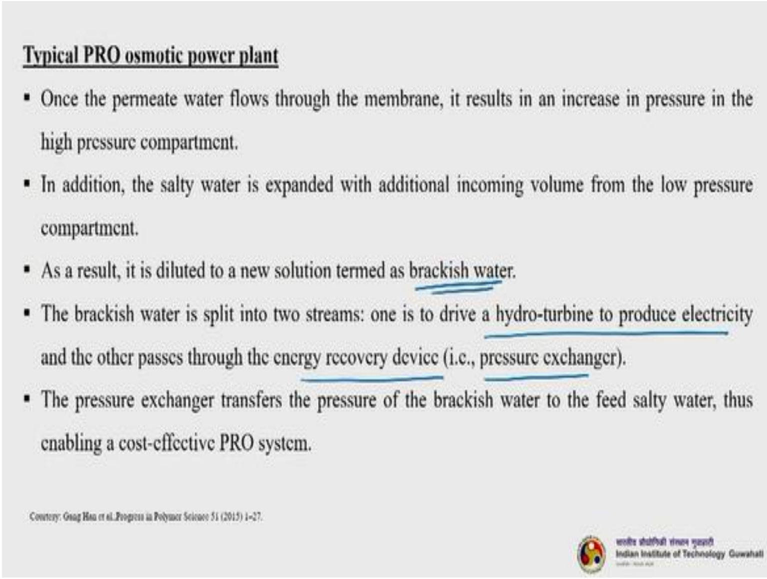

Once the permit water flows through the membrane, it results in an increase in the pressure in the high pressure compartment. In addition salty water is expanded with additional incoming volume from the low pressure compartment and as a result, it is diluted to a new solution term as brackish water. We are calling it brackish water because we know eventually its concentration is getting decreased.

So the brackish water is split into two streams: one is to drive the hydro turbine to produce electricity, and the other passes through the energy recovery device that is the pressure exchanger basically. So the pressure exchanger transfers the pressure of the brackish water to the feed salty water, thus enabling a cost effective PRO system. So this is how pressure retarded osmosis is being utilized to generate electricity.

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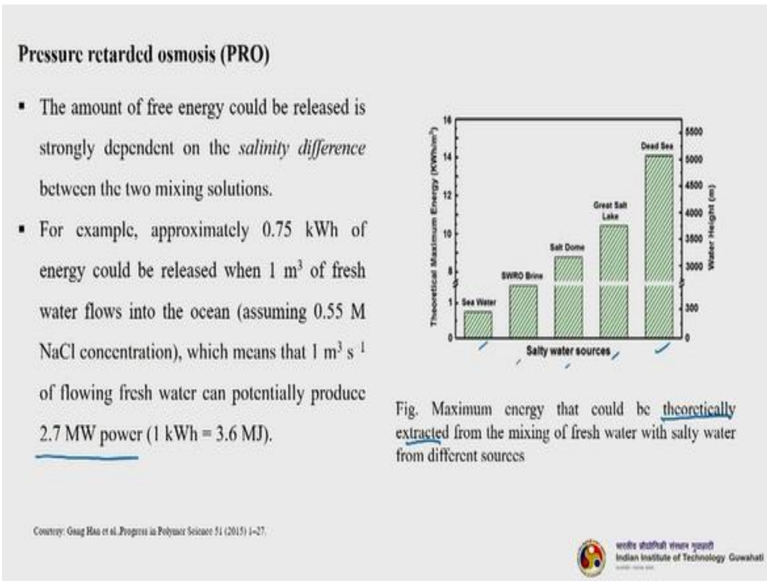

Now see you can understand that the generation of the electricity through this particular system is quite low as compared to the generation of electricity with other processes, Okay? Now, however, if we can generate electricity while, thereby whenever simultaneous carrying out desalination of sea water or brackish water then why not, it is a win situation.

So you can see this particular scheme figure you can see this. The amount of free energy could be released is strongly dependent on the salinity difference between the two mixing solutions, Right? So what is the concentrated of the concentration of the salt inside the seawater or the concentrated solvent and what is the salt concentration in the fresh water.

For example, approximately 0.75 kilowatt hour of energy could be released when 1 meter cube of fresh water flows into the ocean assuming 0.55 Molar sodium chloride concentration, which means that 1meter cube per second inverse of flowing fresh water can potentially produce 2.7 megawatt power. So you can see here maximum energy that could theoretically be extracted, this is theoretical we extracted from the mixing of freshwater with salty water from different sources.

There are different things like sea water, so this is SWRO brine; this is salt dome, Great Salt Lake, and then the Dead Sea. You know that in the Dead Sea near Israel. Okay? So you know, the concentration of the salt is much, much higher than any other sea. So that is why you can see this theoretically more power can be extracted.

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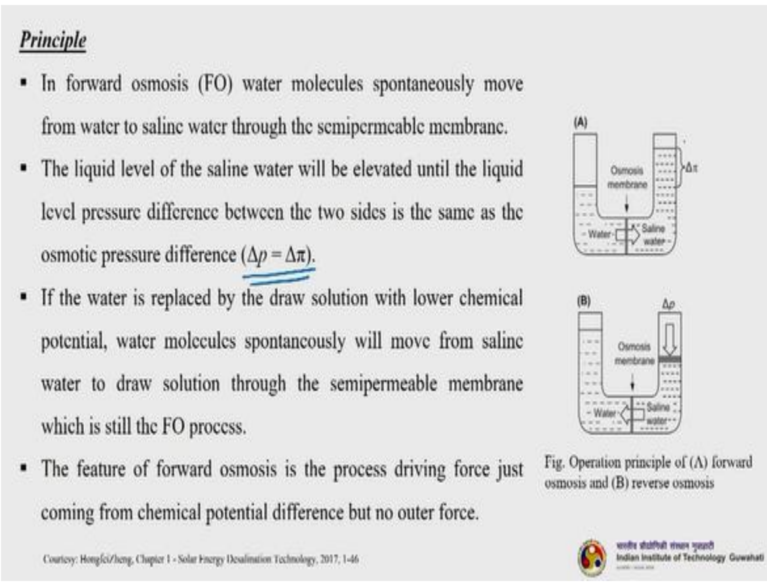

So let us now understand what is forward osmosis and what are its applications. So nowadays, forward osmosis applications are increasing, because of the simplicity in operation and low energy consumption. In many industrial processes, so let us try to understand what it is, so forward osmosis is the process of spontaneous water diffusion across a semi permeable membrane in response to a difference in solute concentration.

So this is how osmosis have to express, we already discussed it many times in forward osmosis water molecules from saline water moved through the semi permeable membrane toward the draw solution, which is maintained at a higher concentration than the feed solution. So, FO mainly uses osmotic pressure gradient and not the hydraulic pressure gradient, okay? So this is your usual RO, so when you have to apply a delta p to overcome the delta Pi.

So, in forward osmosis water molecule spontaneously moved from water to saline water through the semi permeable membrane. The liquid level of the saline water will be elevated until the liquid level pressure difference between two sides is same as the osmotic pressure difference delta p becomes delta Pi, Okay? So everything is happening due to this delta Pi. Okay? We are not pressurizing the system like in case of RO.

So if the water is replaced by the draw solution with lower chemical potential, water molecule spontaneously will move from saline water to draw solution through the semipermeable membrane which is still the FO process. The feature of forward osmosis is the process driving force, just coming from chemical potential difference but no outer force. There is no outer force being applied here.

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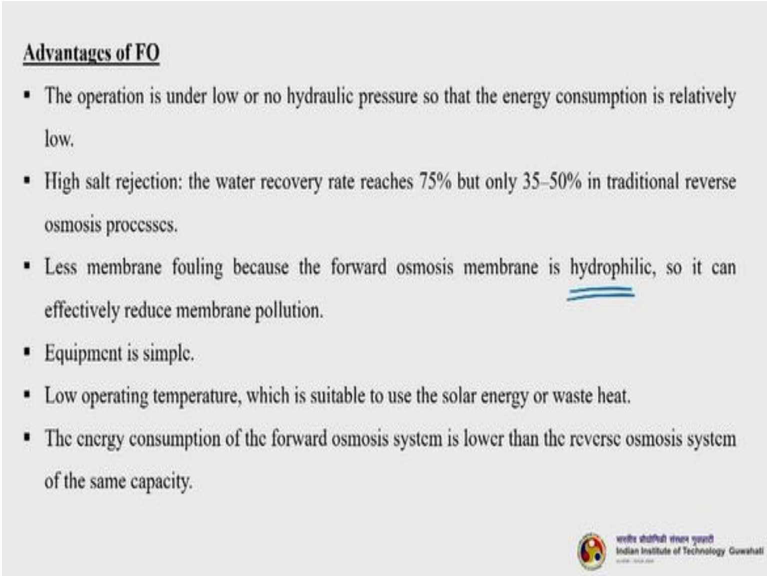

The operation is under low or no hydraulic pressure, so that that energy consumption is relatively low. High salt rejection; actually the water recovery rate reaches about 75%, but only 35 to 50% in traditional reverse osmosis processes, less membrane fouling because the forward osmosis membrane is hydrophilic, Okay? So it can be effectively reduce membrane pollution. Equipment is relatively simpler.

Low operating temperature also, which is suitable to use the solar energy or waste heat. So the energy consumption of the forward osmosis system is lower than the reverse osmosis system of that same capacity.

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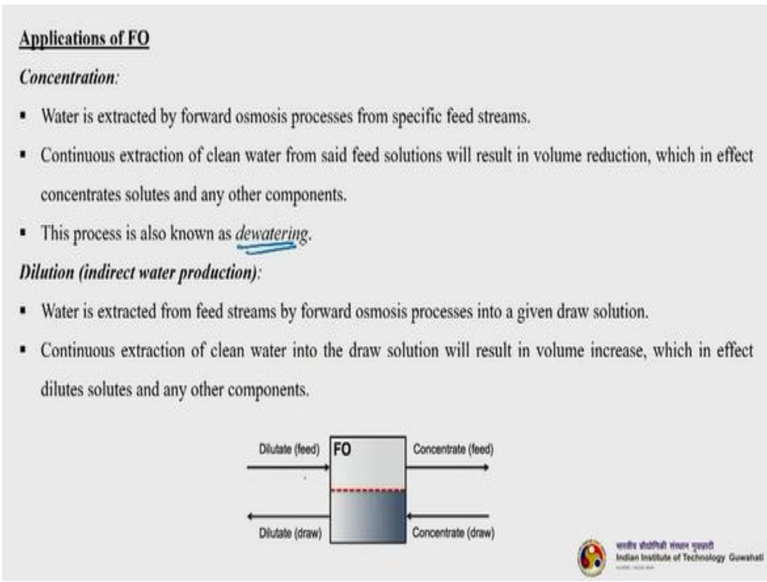

So, there are various applications of forward osmosis, the first one is concentration. So water is extracted by forward osmosis process from a specific feed streams there by concentrating it. Continuous extraction of clean water from the feed solutions will result in volume reduction, which in effect concentrates solutes and any other components that is present, or we want to concentrate.

So this process is called as dewatering, basically what they will be water. So the next is dilution or it is called indirect water production. So water is extracted from feed streams by forward osmosis process into a given draw solution. You can see here, dilute, diluted or feed is being poor pathway ecosystem, and we get concentrated feed here. So here the concentrate of the draw solution is being feed at the bottom side, and you get the diluted here.

So continuous extraction of clean water into the draw solution will result in volume increase within in effect dilutes solutes and any other components.

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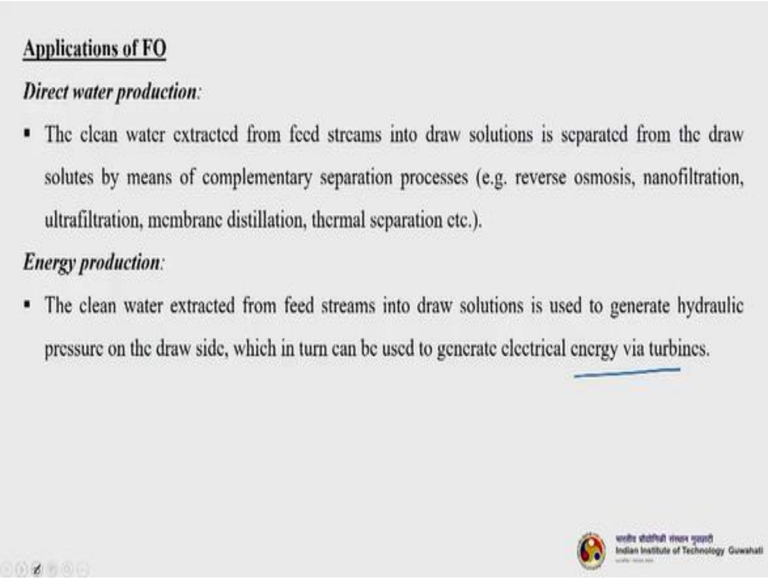

Then the next application is direct water production; the clean water extracted from feed streams into draw solutions is separated from the draw salutes where means of complimentary separation processes is for example; reverse osmosis, nano filtration, ultra filtration, membrane distillation as well as thermal separation etc. and it can also be used for the energy process.

Clean water extracted from feed streams into draw solution is used to generate hydraulic pressure on the draw side, which in turn can be used to generate electrical energy by turbines. But anyway this amount of energy which will be produced by FO will be always much, much lesser than that will be produced in the PRO system, Okay?

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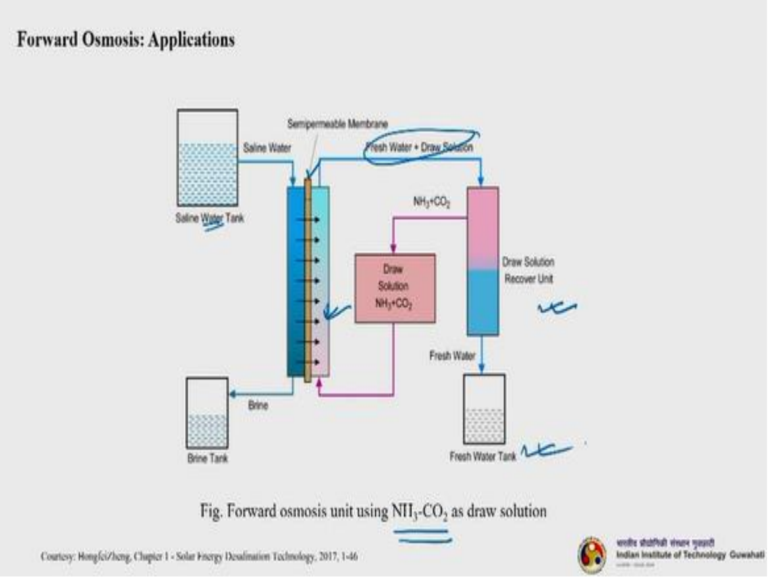

So this is an example of the forward osmosis application. Here you can see this saline water is being feed, Okay? Is being paired to the, this one, forward osmosis process and this is a semipermeable membrane here, okay? To one side and the other side were using ammonia carbon dioxide is the draw solution here, Okay? So, this is the draw solution tank actually recovered unit.

So, ammonia and carbon dioxide is being paired to the opposite side and water from the concentrated the saline water will diffuse to the membrane, and it will embrace the draw solution here, then you will get a fresh water into solution here basically, and it is the solution gets diluted basically, then you can separate it and take fresh water and separate fresh water from the process, Okay? From the stream.

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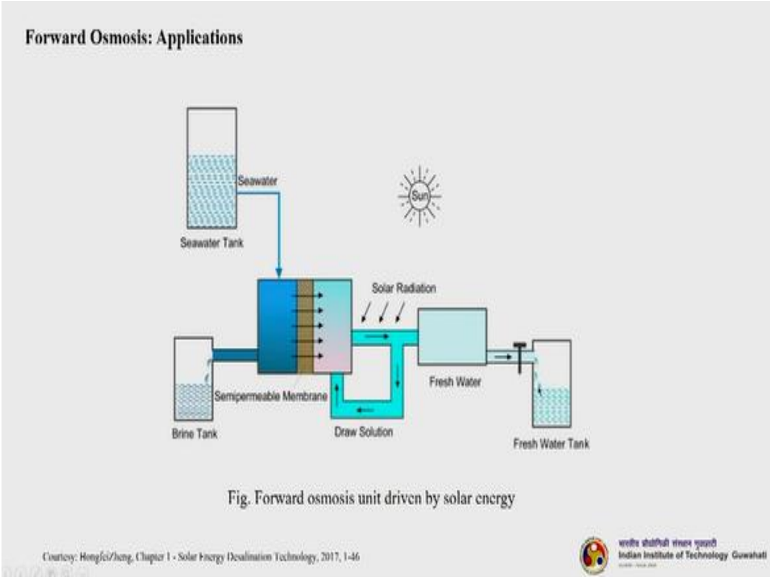

And this is another application, in which actually the solar radiation is being used to accomplish forward osmosis system. Again the same process yet there is semi permeable forward osmosis membrane, in which seawater is being feed to the one side. Okay? And a freshwater, which is being fed to this forward osmosis system as it draw solution, Okay? Is getting enriched, or by your water that is diffusing from the saline water to the draw solution side.

So solar radiation plays an important role here, so instead of hitting it instead of this one using any other thermal processes to hit this draw solution, solar radiation can be used to hit it. And then you, it will come to a tank where you can get the fresh water.

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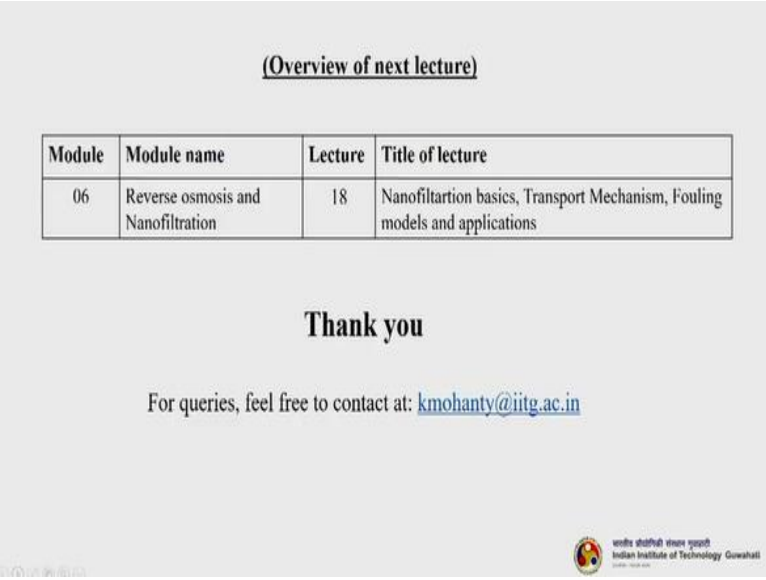
So, most of the text is being up to todays lecture and taken from Richard Baker, Okay? K. Nath and little from Mulder, so you can refer these books, Okay? So thank you very much. **(Refer Slide Time: 44:50)**



And next lecture will be nano filtration; will learn what is nano filtration and what is the transport mechanism and different fouling models and different applications of nano filtrations. So thank you very much once again and if you have any queries, please feel free to write to me kmohanty@iitg.ac.in. Thank you very much.