Wastewater Treatment and Recycling
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Lecture – 46
Tertiary Treatment Membrane Processes

Hello friends and welcome back in this next class which is 46th lecture for this course Wastewater Treatment and Recycling. And we have been discussing the advanced treatment systems this week. So, we started the week with the basic idea or requirement and need of the advanced treatment systems then we talked about the nutrient removals; the removal of nitrogen and phosphorus through biological and chemical procedures. And in the previous class we discussed about the adsorption and ion exchange systems which are used for advanced treatment or tertiary treatment of the wastewater.

So, this lecture we are going to discuss the another class of treatment systems; it is not just one single treatment or one type of treatment there are various sub like variety of units which can be used as a advanced treatment systems. So, this is basically the units which use membrane for filtering the water and those kind of like the membrane filtration what we typically call or membrane processes for the tertiary treatment. So, that is what we are going to discuss this week; the different membrane processes or the different membrane filters that are used for the tertiary treatment or the remaining contaminant removal from the wastewater.

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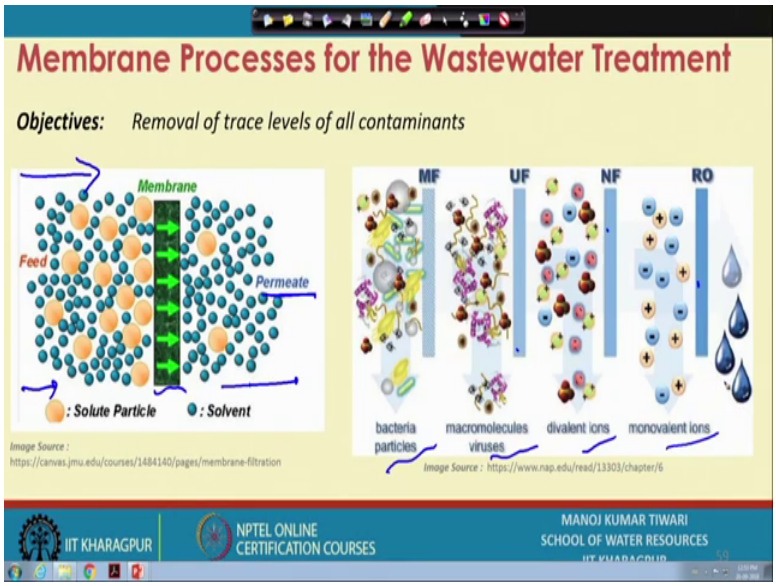

So, the objective of the membrane processes is the removal of trace level of all contaminants. All means almost all contaminants; bearing few dissolved gases if we go to the higher level of the membranes like reverse osmosis system we can technically remove all type of contaminants from the water.

The process is straightforward pretty simple. So, what we have we have a membrane which is kind of a semi permeable membrane and we have basically feed water coming from one side. Feed water is the water which is having contaminants in it these contaminants of course, the membrane processes are not used for removal of the suspended materials or those kinds of things because that is that can be removed in a much simpler way with much economic systems. The membrane process are primarily targeted to remove the contaminants which are difficult to remove from any other system. Because the membrane processes are usually recognized as the most energy intensive treatment systems that are used these days.

The reverse osmosis or RO systems are kind of the most energy intensive treatment systems. So, in order to kind of ensure that the cost of the treatment systems are lower, we remove all other things which can be removed from other steps and then we go for the high end treatment systems like the membrane processes for the removal of remaining trace level of the contaminants. It is could be microbial contaminants, it could

be dissolved salts, it could be even like monovalent ion or those kind of thing can also be removed.

So, what happens we have a feed water coming in as we said which is having various contaminants in it, various fine contaminants in it, then these processes usually operate under pressure a pressure is employed the water passes through this membrane and the contaminants majority of the contaminants are actually retained.

Now, what retains what we will discuss, but then these contaminants are retained on the one side and the water which we also called as permit passes through the membrane, and the one which retains becomes the concentrate or reject that way.

So, we variety of systems like microfiltration, ultra filtration, nanofiltration, reverse osmosis with; like this microfiltration can retain the mostly bacteria particle, ultrafiltration can retain the macromolecule viruses, nano filtration can retain divalent ions RO can retain even monovalent ions. So, it is not that RO will retain only monovalent ion RO can retain actually all of this because the size is smaller, nano filtration can retain these divalent ion micro molecules bacteria particles all. The ultra filtration can remove the bacteria particles, micro molecules all that way, but probably will not be able to remove the divalent and monovalent ions.

Similarly, nano filtration will not be able to remove the monovalent ion. So, that way we have the retention spectrum for these different processes ok.

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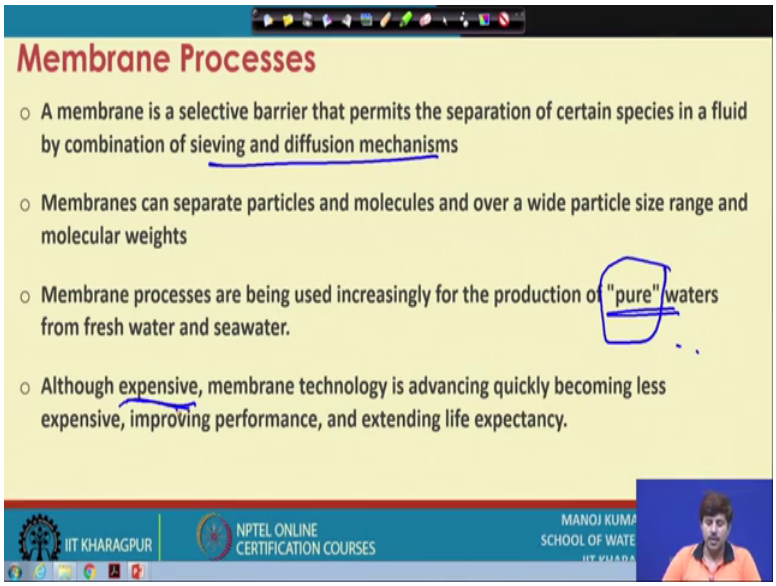

Now, if we see the membrane processes. So, membrane is selective barrier that permits the separation of this contaminant a species in a fluid by combination of sieving and diffusion mechanism. So, these are the two major mechanisms which work. Sieving means just filtration see about the larger particles. And there is a diffusion which also acts upon so that is in combination the removal is there in these different membrane types.

So, this membrane can separate particles and molecules over a wide particle size and drains and the different molecular weights. The processes are being used increasingly for production of the pure water what we call, even from the fresh water and sea water and for wastewater recycling also. So, if like in Singapore the new water is recycles this domestic sewage as we discussed earlier through RO system and then augment it to the domestic water supply. So, they need pure water because they are putting it through domestic supply system. So, for that pure water they eventually go to the membrane system.

These membrane systems are quite expensive, but kind of it is quickly becoming more popular and the cost is also people are trying to bring cause down of this membrane system ok. There is another problem of the large wastage of the water volume in the form of reject water. So, that is also people are working on to reduce that.

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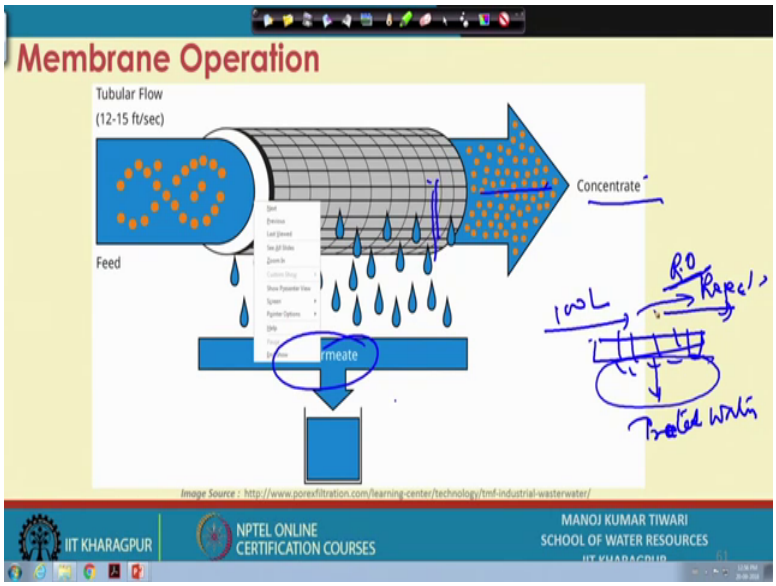

So, what happens in the membrane operation we typically have a kind of feed coming into the membrane system, and then the if like particularly the water passes through this membrane pure water passes through membrane and is collected in the form of permit, whereas the contaminated part. So, membrane will never be able to give a 100 percent output in terms of water. If we are having let us say a membrane and we are pushing let us say we are supplying 100 liter of water. So, some water passes through this membrane, but some water goes as a reject what we call or a concentrate ok.

So, this is called Membrane reject or if it is a RO process. So, RO reject is a pretty common term these days. So, RO reject and then this is your treated water. So, it is a simple mass balance, because a membrane does not remove the contaminant completely it is just remove from these treated portion of the water and passes it through with the reject.

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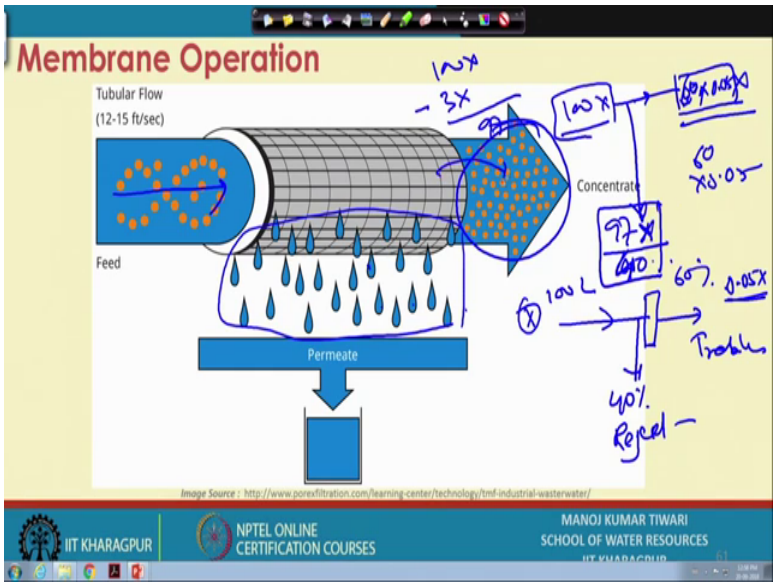

So, for that matter let us say if you are getting 100 as we are saying let us say 100 liter of water is being passed through a membrane and this membrane is say providing 60 percent the treated water and 40 percent is going as reject. So, with just simple mass balance we can identify what would be the concentration, like if let us say here the contaminant concentration is x and here the contaminant concentration is say 0.05 x say 90 percent removal ok.

So that means, this the 100 liter has x concentration, this much mass came into the system and how much mass left out the system. So, because we got just 60 percent flow so that means or 60 liters say that matters 60 liters into 0.05 x ok. So, 60 into 0.05 x mass left, so remaining mass is actually like if we subtract this 100 x minus if we multiply 60 with 0.05. So, say this will become 3, so 100 x minus 3 x that means the 97 x mass has come here. And this 97 mass 97 x mass is actually in just 40 liter of water. So, 40 liters if you divide we can get the concentration that way.

The mass which is coming in here will be going out along with the concentrate or reject. So, the water which is purified you earlier concentration earlier amount of the contaminant in this water is actually transported here. So, reject that way we will have much higher concentration that is why we call that as a concentrate, whereas the permit will have almost no concentration very little concentration.

So, that way these membrane systems work.

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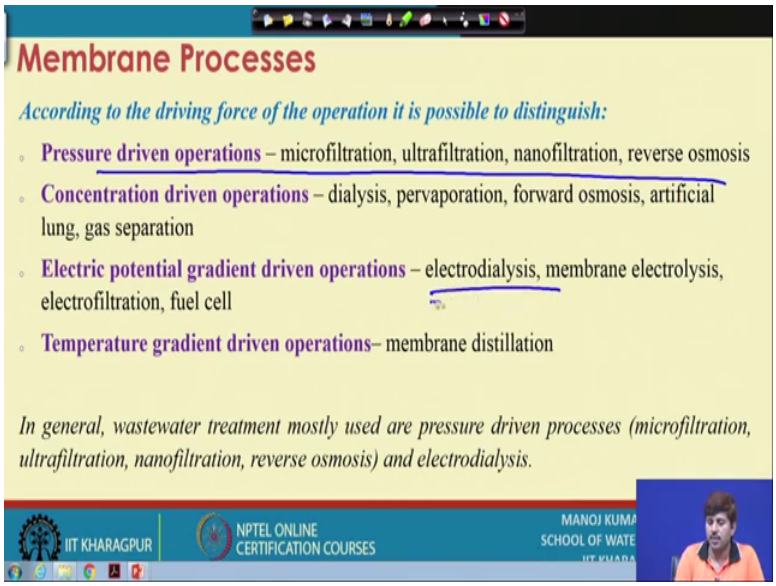

These membranes are derived, there are various diriving forces for the operation of membrane there are pressure driven operations which are microfiltration, ultrafiltration, nanofiltration, reverse osmosis. There are concentration driven membranes in the form of dialysis, forward osmosis, artificial lung all those things. There are electrical potential gradient driven operations in the form of electro dialysis or membrane electrolysis. And there are temperature demands when we talk about the membrane distillation where we kind of vaporize it and then vapor passes through the membrane so the distillation process occurs.

In wastewater treatment generally these pressure driven operations and electro dialysis are the one which is typically used.These days forward osmosis people have also started using, but the field applications are very limited still.

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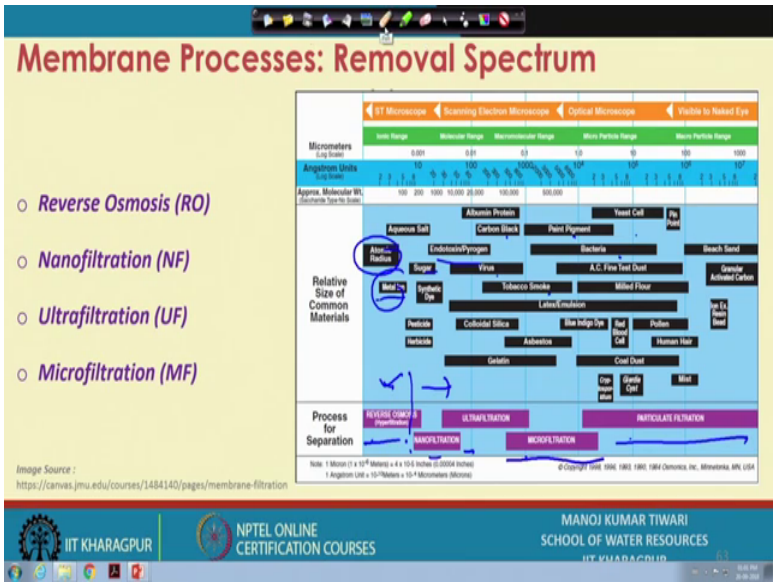

Now, if we see the removal spectrum of these membranes what they can remove. So, depending on these various types of kind of contaminants if we see the yeast cell pigment, bacteria, thus tobacco, smoke, viruses, carbon, black there are endotoxin, sugar, aqua salts, metal ions.

So, this is their size range these are in the angstrom units. So, these are the different size ranges. So, the up to the size range of say 1 micron or 1 micrometers typically particulate filtration is able to remove. Then up to 0.1 or little lower than 0.1 your micro filtration will work, up to 0.01 that is equal to kind of 10 nanometers the ultra filtration can work, up to a scale of 1 nanometer your nano filtration can remove. And for the various metal ions or atomic these things which are less than the size of 1 nanometer we need reverse osmosis kind of processes to remove that. So, that way we can have the different process range or removally spectrum of these different processes.

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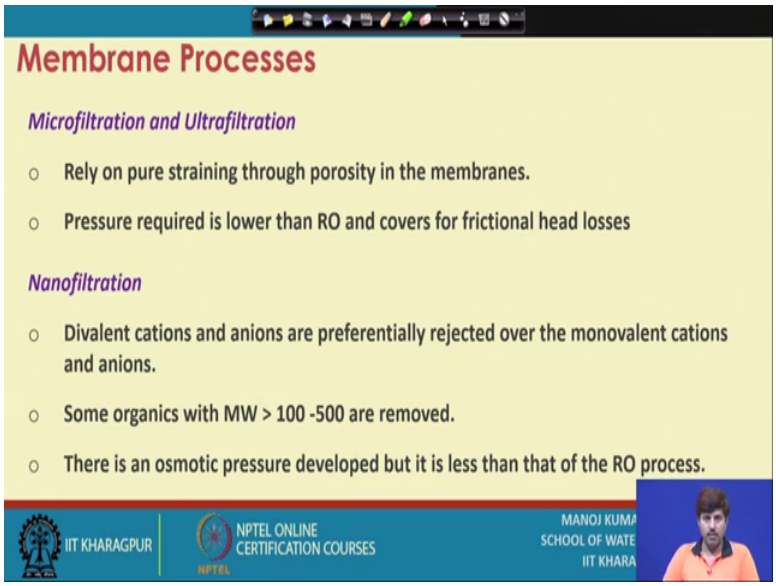

So, if we see these different membrane processes particularly the one which are used in the wastewater treatment. So, the microfiltration and ultrafiltration are essentially just there is a size difference they work on a similar principle. They are just pure straining processes through the porosity of the membrane.

The pressure is needed much lower than RO and which is essential for covering the frictional head losses only. So, there is no additional need of pressure it can actually take place under gravity also, but there will be lot of time required, so because of the higher head losses of the very fine pore sizes. So, in order to overcome that pressure is applied to kind of cover for the head losses which are there so that the flow can be smooth and relatively faster.

The nano filtration are the one where divalent cations and anions are preferentially rejected over the mano monovalent cations and anions. There are some organics with molecular weight greater than 100 to 500 are also removed there is a little development of osmotic pressure, but it is far less than the typical RO system.

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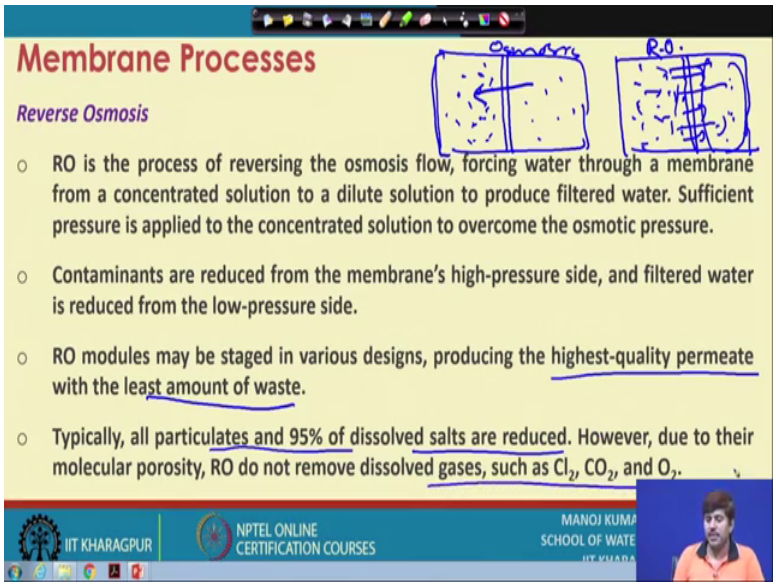

The RO or reverse osmosis is actually the process of reversing the osmosis flow. So, if we see the normal osmosis process of what osmosis is or osmosis is through a semi permeable membrane we allow the water. Let us say this is having a zone of high concentration and this is having a zone of less concentration. So, under normal osmosis process what will happen? That water will pass through this semi permeable membrane to the zone of high concentration in order to neutralize the concentration on either side. But in reverse osmosis this process is reversed under pressure. So, we are having zone of high concentration and other side there is zone of less concentration or say pure water. So, water here is made to pass through this membrane under RO system under pressure to the zone of less concentration or not polluted zone.

So, the idea is to reverse the osmosis process with the application of pressure ok. And this membrane is chosen that it can actually reject all other things except the water. So, just water goes through this clean zone and we get a kind of clean zone of the water.

So, that is what is the reverse osmosis and as the concept suggests there will be a requirement of huge energy in terms of applying that pressure which can reverse the natural osmotic flow, natural osmotic pressure. So, these contaminants are kind of reduced from the membranes high pressure side and filtered water is reduced on the low pressure side these RO modules may be staged in various design which can produce highest quality permit with least amount of waste. So, how much amount of waste is

being generated initially RO used to kind of generate for 1 liter of treated water 3 liter of waste was generated. So, the kind of the reject used to be 70 percent 80 percent 60 percent that way.

Now the research is kind of on to reduce the reject portion and we have membranes which reject as low as say 10 percent or 20 percent of the water and passes through treats actually almost 80 percent of the water. Typically, through these membrane systems all particulates and 95 percent of the dissolved salts will be kind of removed RO does not remove the dissolved gases the only thing, but otherwise it can actually remove all such sort of things.

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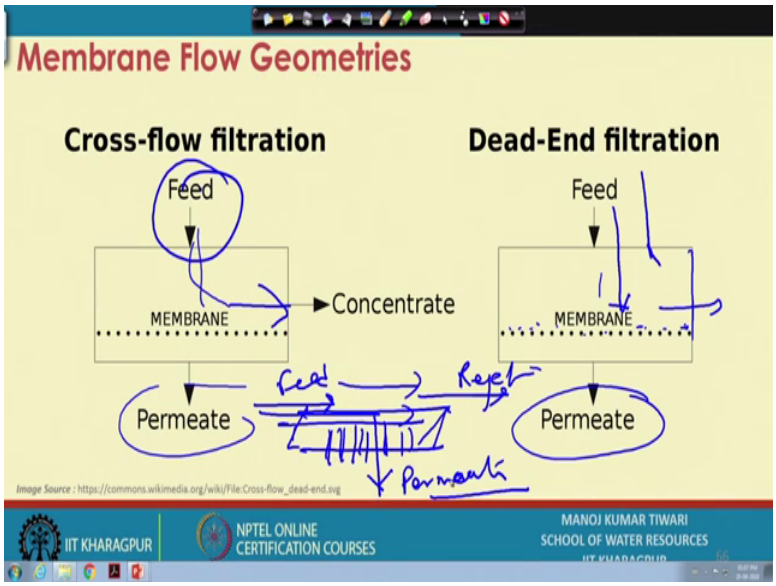

Now, there are flow two flow patterns in such membranes particularly the RO systems. So, there is one something called cross flow filtration and something is called dead end filtration. So, the dead end filtration we provide the feed through the membrane and then we get the permit. So, there is like the direction of feed is vertical to the membrane. So, that the feed has to pass through this membrane of course, the concentrate still goes through, but the feed is pushed through the membrane that way. So, the retention or the kind of falling of membrane is more frequent more common in this one, whereas cross flow filtration we have the different mechanism. Here it is a closed vessel, so the feed will be helped to pass through the cross flow filtration we can have feed coming in here

and then actually the concentrate going in here and the permit going in here. So, feed has a way.

And more so ever more than this cross flow actually the more popular cross flow mechanism is this where we have let us say this is the membrane. So, feed is coming in this direction, permit goes in this direction, permit comes in this direction, this is reject and this is the feed direction. So, the flow through the membrane is just like it crosses through the direction of feed is this is kind of parallel to the membrane and under pressure the flow through these membranes takes place and then it is collected, whereas reject flows through this way.

So, that is what is your typical kind of cross flow modules.

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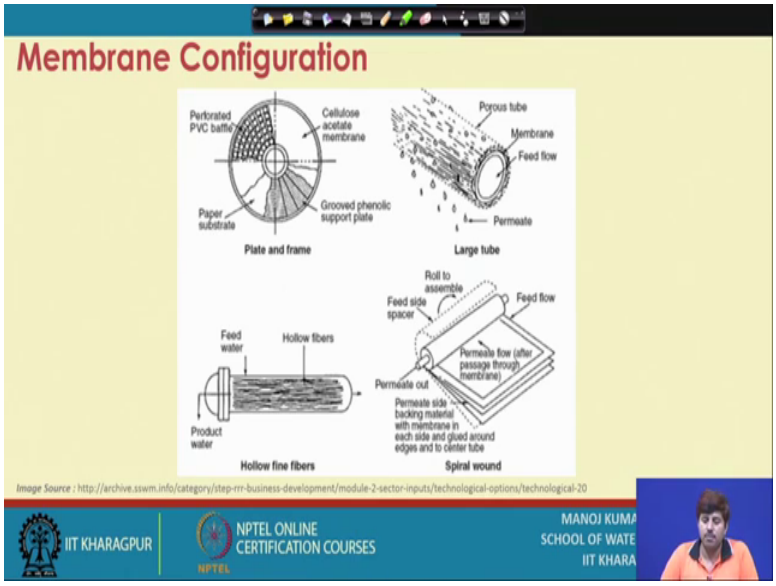

There are various configurations. There are membranes in the plate and frame form, there are large tubes there are spiral bounds membrane hollow fiber membranes.

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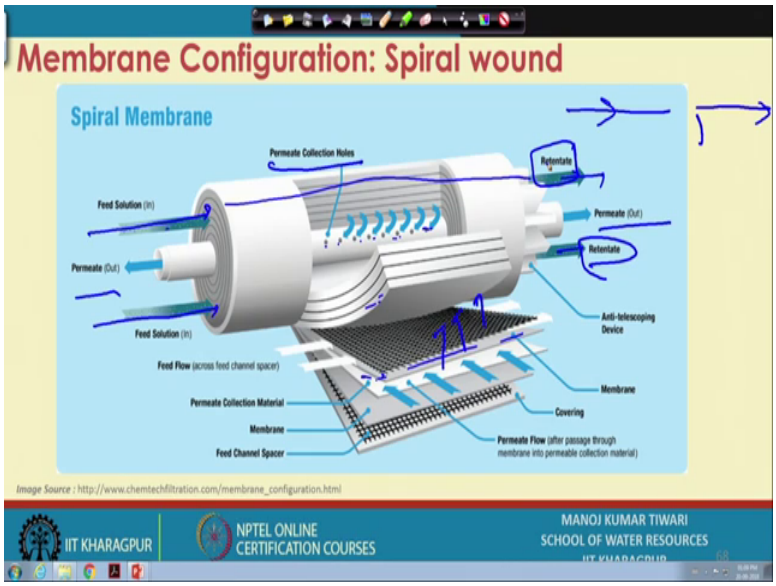

So, how they typically look like I spiral bound membrane will look like this. So, we have these various membrane systems coming in here and you see the feed solution is being put through this and these are the membrane. So, they are kind of rolled and rotated over here. So, what happens: that the feed is actually entering in between like these places and under pressure it is basically permitting through these membranes, its passing through these membranes and eventually getting to these holes over here. So, these are the permit collection holes. So, the treated water the feed water once it is passes through the membrane. So, that become basically permit or treated water enters through these holes and then is collected through these permit out channel.

And the reject water or kind of concentrate what we call or written end will actually be keep on because the feed solution we are passing. So, will be keep on passing through this processing through these horizontal lines and then will be collected over here as a written end or as a concentrate right. So, it is a cross flow module that way, you can see that the kind of flow is this way and reject is also going this way this is your flow this is your reject flow and the permit is vertically kind of or radially crossing through this and entering into these permit hole. So, that way it is collecting ok. So, that is what is the configuration of a typical spiral membrane which is a cross flow membrane.

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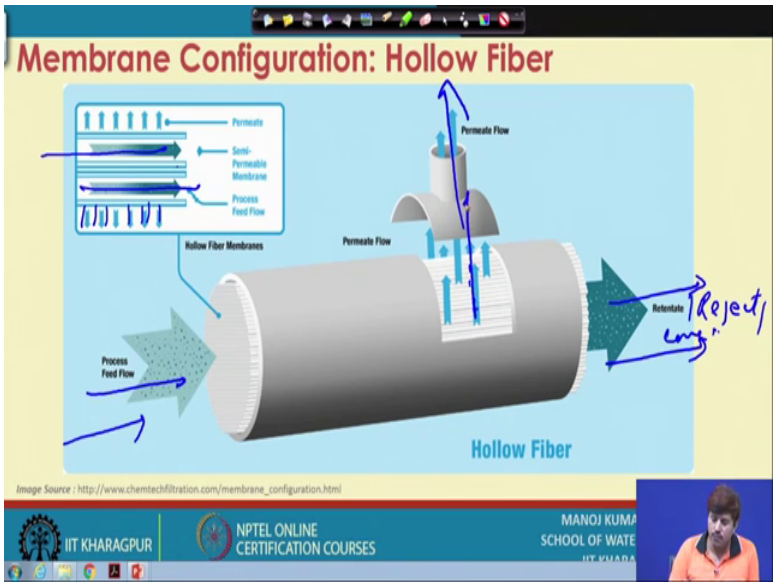

Then we have various like there is hollow fiber membranes ok. So, these hollow fiber membranes are there are various kind of hollow fiber membrane will be something like this ok. So, we can see that there is semi permeable membranes over here. So, water is flows through these hollow tubes and then through these membranes it is actually again comes out. So, through these membranes it will be collected and then permit flows through this channel that way whichever is provided and the inflow which is there and the retaining or concentrate will go from the other side or reject will go to the other side.

So, written end is also called reject or concentrate right. So, this is also again a kind of cross slow module, you are having the your feed water passing through this per reject water going through this and in between your permeate is flowing through vertically.

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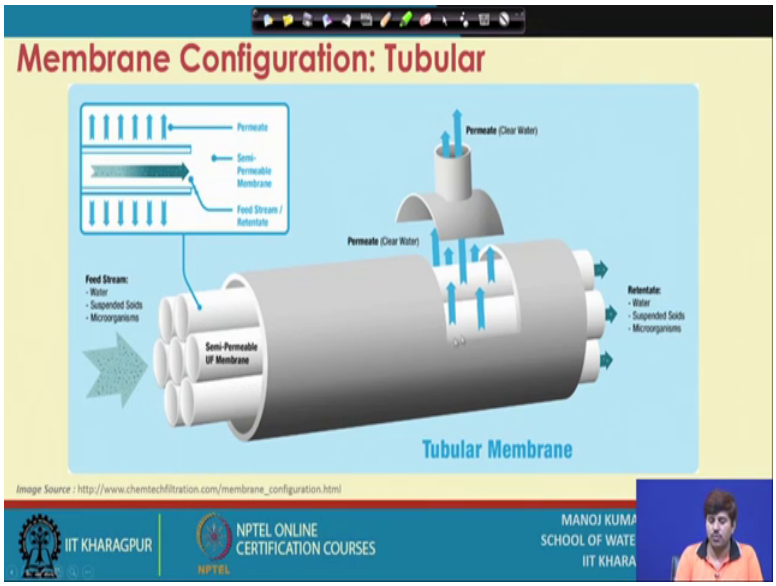

So, this is these are kind of cross flow membranes which are more popular, because they do not have that kind of like that much of falling problems as we see in the dead end module modules. So, this is a tubular module. So, much larger tubes over there similar to the kind of earlier one that we saw hollow fiber ok. So, here we have semi permeable membranes, over there tubular membranes flow is pass through this permeate is collected rejected goes there.

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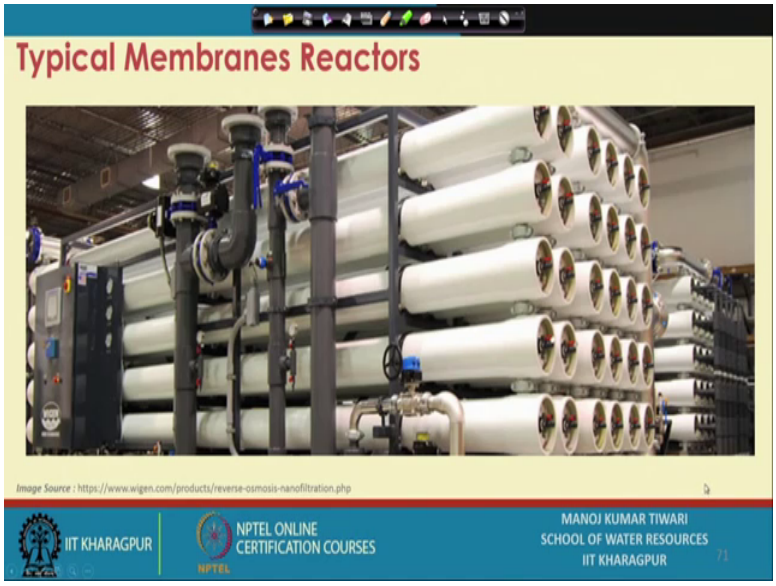

So, that way we can have a typical membrane reactor will look like this ok. So, in an Industrial system, there is kinds of large tubes over there. So, from top because they are work under pressure, so from drop they are well cased nothing will be seen, but inside how it is there we just discussed we just saw the certain configurations of that.

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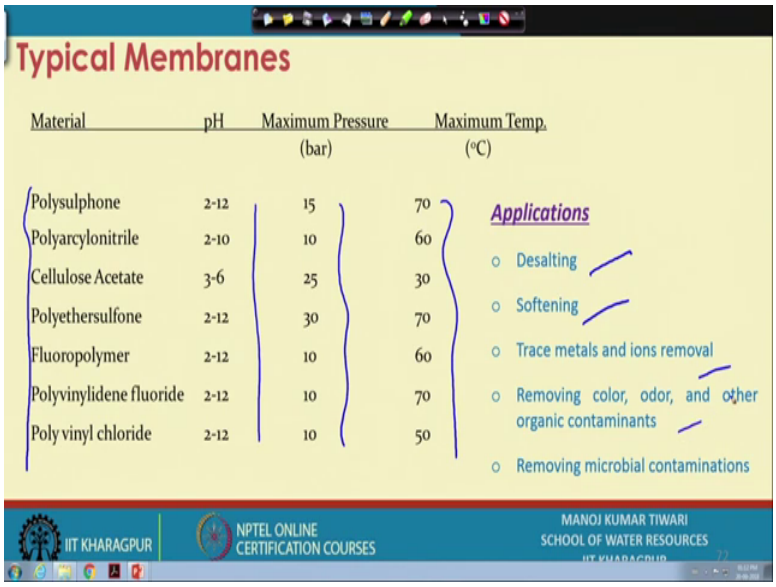

If we see the typical membrane materials, so there are like various kind of membrane materials, there are various pH ranges they work, there are various pressure ranges and the temperature ranges in which they work. The application of the membrane processes are for desalting, softening, trace metal and iron removals removing color order other organic contaminants removal microbial contaminants. So, they can almost remove all things other than these some of the dissolved gases as just we.

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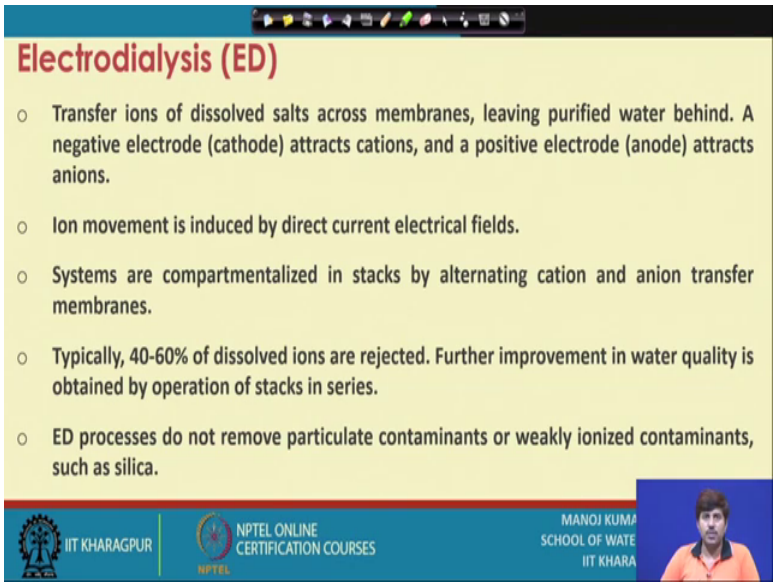

We were discussing. The other membrane process which is used particularly in the industries again for the treat tertiary treatment of wastewater is electro dialysis.

So, electro dialysis is a process where basically the ions which are they are dissolved in the water various different type of ions cross through the membranes and these membranes which kind of are there. So, they are selective ion selective membranes. So, there would be kind of cationic membrane an ionic membrane. So, depending on the type of membrane it is it will either allow just cation to pass through or an ion to pass through. And then if it is passing cation it will retain all the anions if it is passing anions it will retain all the cations ok.

And then we place two electrodes one positive and one negative electrodes on the either end to attract these ions. So, these ions move towards electrode and because of these selective barriers some will pass through some will retain and as they kind of. So, with alternate channel system we get ions which kind of we have multiple channels over there and in the alternate channels these ions gets collected, because they are retained from the membranes which are there on the other side. So, we will just see then it will get more clear that way.

So, this is a compartmentalize systems which is tagged by the alternate cation and anion transfer membranes and typically 40 to 60 percent of dissolved ions are rejected in this one. We can kind of put this again in a series, so more electro dialysis unit in the series in

order to kind of get the better removal efficiency. And these do not remove the particulate contaminants or weakly ionized contaminants.

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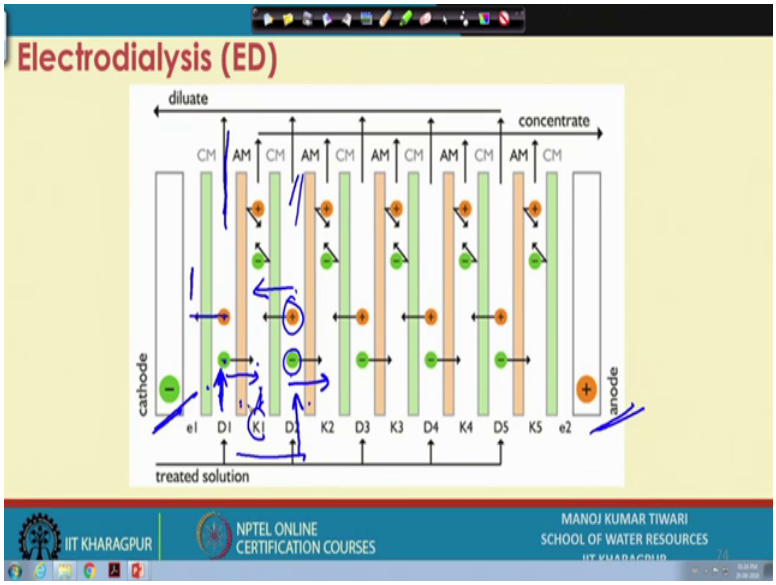

So, they are primarily for the dissolved ions that way. So, what happens in the process of electro dialysis? That let us say we have cathode at one side and anode at one side. So, the kind of water which is supplied in these alternate channels ok. So, if let us say we are putting water in here ok. So, what happens that: this water will be having the ions cations and anions; now the anions here will get attracted to a node, whereas, cations will get attracted towards the cathode right.

So, we have a cationic membrane where cations can pass through this membrane. So, they will leave the system they will come in this zone and similarly we have a anionic membrane on this side. So, these anions will actually pass through this membrane because they are attracted towards anode. So, they want to move in this direction and there is a membrane which allows them to move. So, they will move in this direction. And that way the cation the like cations moves in this direction and ions moves in this direction. And that the final water which is coming out of this channel will be ideally free from these cations and anions.

Now, what happens similarly we pass the inflow through a another channel leaving one alternate channel ok. So, what will happen same thing will happen here these anions will be attracted towards anode they will pass through this anionic membrane and these

cations will be attracted towards cathode they will pass through these membranes and we will get like water devoid of these cations and anions. Now let us see what happens in this intermediate channel.

So, what happens in this intermediate channel let us clear this out and then we see this. So, what happens in this intermediate channel; these anions have passed through this anionic membrane and they are willing to go towards anode they are attracted towards anode. So, they will further willing to go in this direction, but it is a cationic membrane here which will not allow the anions to pass through this. So, there is a membrane which restrict them to pass through. So, they will actually be rejected. They will not be allow to pass through they do not want to go in this direction because there is a repulsion in the form of cathode over here. So, they want to move towards the anode side, but they want to move towards anode side, but this membrane does not allow to move them towards anode.

Similarly what happens to the cations which has come crossing this cation membrane for in the pursuit of going towards the anode. Again they will further like to move through the move towards the cathode, but there is a anionic membrane which again stops them doing so. So this anionic membrane will not let them will not let these cations pass through this anionic membrane towards the cathode. Now they cannot go towards this side because there is a repulsive force in the form of anode. So, their movement is they want to move towards the cathode side, but this anionic membrane in this in their way will not let them go. So, they are also rejected that way.

So, what happens eventually that your anions has passed through this channel cations has passed through this channel, now because cations cannot go there so they will rejected and remain in this similarly your anions cannot pass through the cationic membrane. So, they will also be rejected and remain in this one. So, in this channel the water that you get will have a higher concentration of cations and anions because your cation and anion have passed through this system. So, this becomes your kind of the flow that you get from here becomes your reject and the flow which you are getting from this becomes your clear one; clear water that way.

So, this like flow coming in here goes to the concentrate. So, this is the reject or concentrate whereas, since the anions and cations has passed to these alternate channels.

So, this is your diluted water or permit water or treated water that way. So, this is the concept of working of the electro dialysis step.

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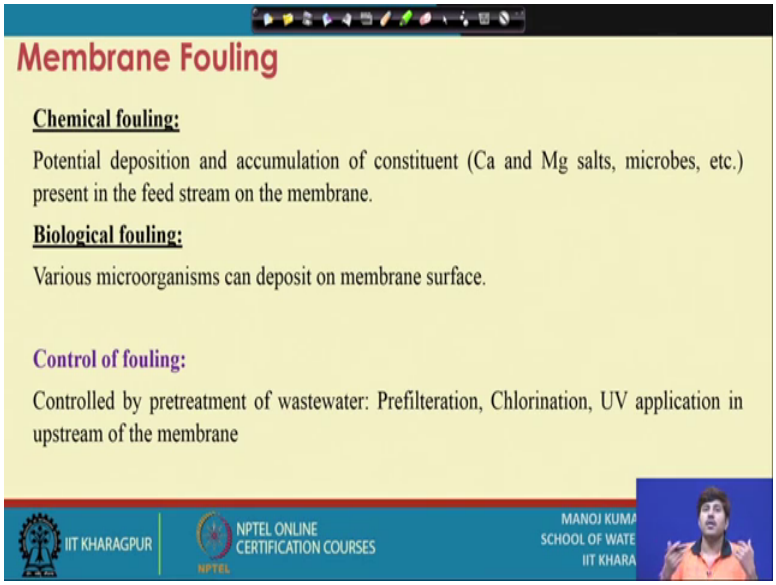

Now, one of the prime problems of the membrane operation is membrane falling. This membrane falling could be in the form of chemical falling where the potential deposition and accumulation of the chemical constraints like calcium magnesium salt various these things takes place. And it could be a biological falling where the microorganisms can be basically deposit on the membrane surface. The falling can be controlled; there are kind of ways to control the falling. So, it can be controlled by the pretreatment of waste water. So, we can go for pre filtration for removing the suspended particles, we can go for chlorination for bacterial or those kind of thing UV application upstream to the membrane. So, these are some of the pre treatment methods which can control the falling.

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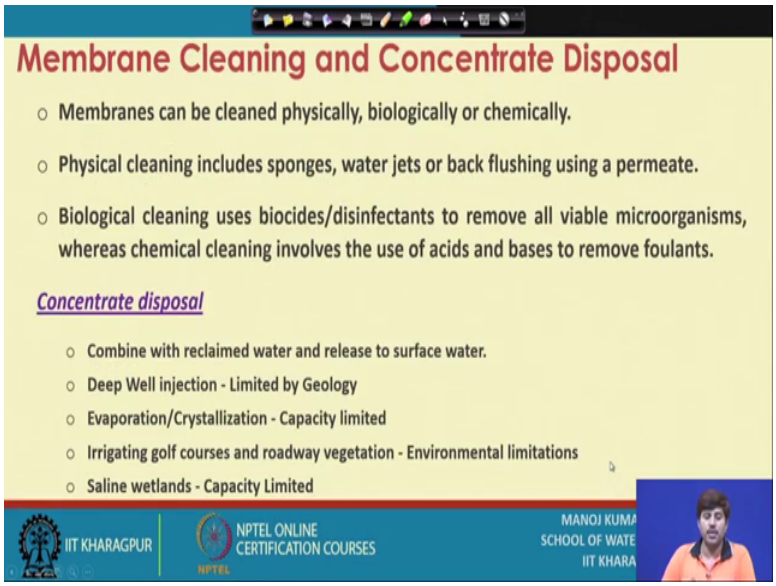

But even if membrane has kind of block that ways it needs to be clean and the membrane cleaning can be done again physically chemically or biologically .Te physical cleaning includes sponges water jets or back flushing using a permeate; the biological cleaning uses bio sights or disinfectant to remove the microorganisms present in there, whereas chemical cleaning involves the use of acid and bases to remove the pollutant and the pollutant which has been deposited on the membranes. Then the concentrated concentrate that is received or the reject that is received membrane reject is kind of combined with the reclaimed water and it may be put to the deep well injections where there is kind of how much you can do this deep well injection will be governed by the geology of the system. We can go for evaporation and crystallization as well, but then again a quite energy intensive process and how much water you are going to evaporate that is capacity limited. It can be used for irrigating golf course and roadways and vegetations. So, there are environmental limitations because there is a lot of salt and if they deposit on these lands. So, there is possibility of kind of other potential environmental problems. And it can go to the saline wetland which is again capacity limited how much you can dispose.

So, membrane concentrate or what we call at RO reject those kind of things are a big environmental issues people are working towards kind of seeing how we can deal with these things.

So, this we will conclude the lecture here; we will conclude this particular class here. And, in the next class which will be the last for the week we will discuss some of the remaining tertiary water treatment steps.

Thank you.