Physico-Chemical Processes for Wastewater Treatment
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Lecture 41
Wastewater Treatment by Membrane Processes - I

Good day everyone, and welcome to these lectures on Physico-chemical Processes for Wastewater Treatment. So, in the previous lectures, we have already discussed various treatment methodologies that can be used for treatment of water or wastewater for various uses. So, previously we have discussed different treatment methods including the flow equalization basin, aeration, coagulation-flocculation, settling, filtration, adsorption, ion exchange. So, these physico-chemical processes we have already studied.

Now, in addition to these processes, there is another category of treatment process which is called as membrane processes which are nowadays used very commonly for treatment of water or wastewater, depending upon the type of pollutants are the type of different other categories of material that have to be separated out. So, these membrane processes are very common, and they are used variously in the industries as well as in the usual treatment process. And in fact, they are used very commonly in the household water treatment units which are installed in each and every residences nowadays.

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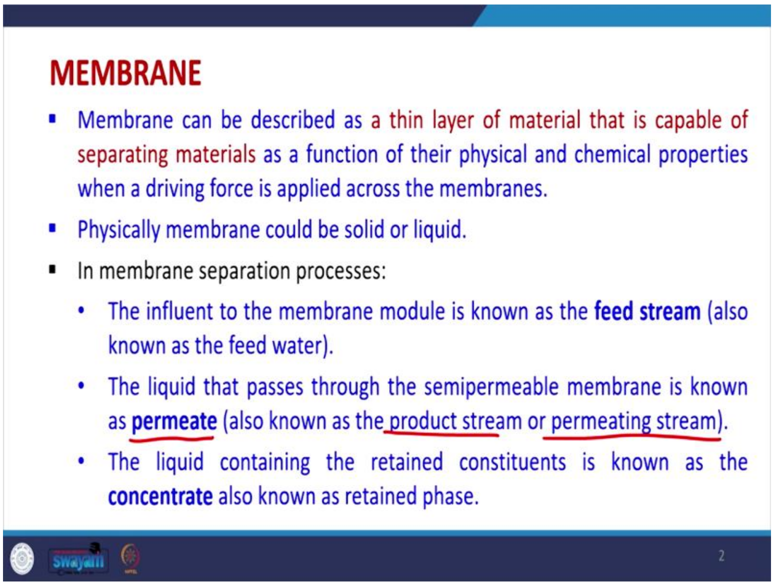

So, going further membrane, in all these membrane treatment processes, one thing which is the most common is the membrane. So, membrane can generally be described as a thin layer of material that is capable of separating materials, different types of pollutants et cetera. And these the separation that happens, it is a function of different physico-chemical properties of the membrane itself, and when different types of driving forces are applied across the membrane. So, we are understanding two, three things out of this.

One thing is that there is a membrane which is like a separating unit, and which works on the basis of filtration or some other mechanism. And these membranes have some physico-chemical properties, which come via we produce these membranes. So, these physico-chemical properties may include the size range of the pores, the various chemical stabilities et cetera, whether they are stable with respect to chemical, how much stability is with respect to different types of pressures under which they can be operated.

So, all these depending upon these physico-chemical properties, we can use a driving force which may be a pressure driven driving force or electrochemical driving force. So, depending upon that we can apply a driving force and based upon that separation happens. Physically membrane could be a generally be solid, it can be liquid as well. So, in the membrane separation process, what we do is that, we have a influent that goes into the membrane module.

So, that water that has to be treated or the feed stream or the influent that goes into the membrane module, it is called as feed stream, it can be called as feed water as well. So, that is the common name. Second most common name is that after the liquid passes through the membrane, which is generally semipermeable, the liquid which is coming out it is called as permeate, and it is also known as product stream, or permeating stream.

So, any of these names can be taken so, we have a feed stream, we have a permeate. In addition, the liquid containing the retained constituents in which all the material that had to be separated will be present, it is called as concentrate, or sometimes it is called as reject also. So, it can be called as concentrate, it can be called as reject, it can be called as retained phase. So, any of these names et cetera can be there.

So, we have three streams, one is called feed stream, another is called permeate, another is called concentrate or reject. So, these are the common names which are there with respect to different streams which are there in the membrane separation process.

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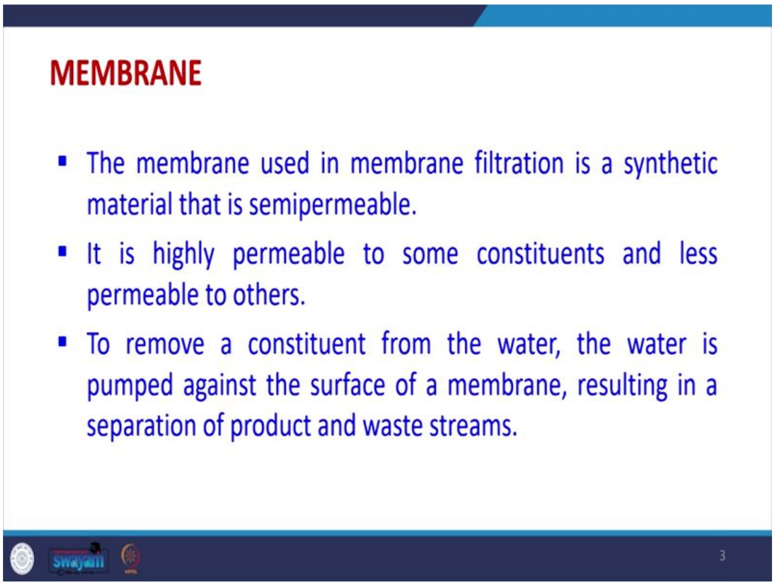

Now, the membrane used in the membrane filtration is a synthetic material. So, that is semipermeable. So, semipermeable means that it will generally allow the water to pass through it, but it will not allow other materials to pass through it. So, it will be like a filtering system for some of the material, but it allow some other material to pass through it.

And that will depend, these things will depend upon the pore size of the membrane and depending upon also that how much pressure can be applied across this semipermeable membrane. This membrane is highly permeable to some of the constituents and less permeable to other constituents as already discussed.

To remove a constituent from the water, the water is pumped against the surface of the membrane, the driving force will depend upon the at how much pressure the membrane can sustain, and when that driving force or the pressure is applied the water will pass through, but the constituent will be retained on the side of the membrane itself, and this will result in a separation of product and waste stream. So, this is how the membrane separation processes generally work.

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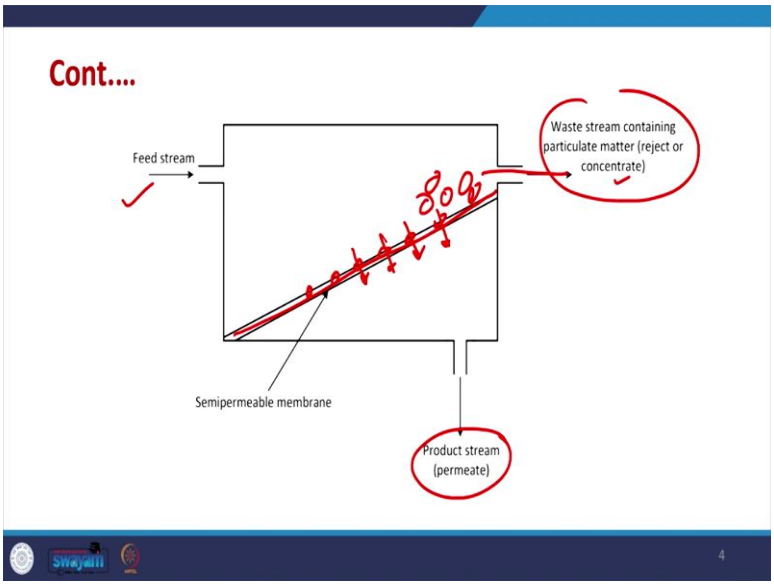

So, if we go further, so, this is like one of the, we can call it. So, feed stream is coming from one side, we have a semipermeable membrane here, and the feed stream will be applied here. And now, depending upon the pressure that can be withstand by semipermeable membrane, that can be pumped depending upon that. Now, this permeable membrane will be having some pores inside. So, it will allow the generally the water to pass through it or some other constituents, but other bigger constituents will be retained on this side, and they generally go along this some amount of water.

So, this is a concentrate, waste stream containing the reject or the rejected constituents will be present in this stream. Now, the water which has passed, so we will be having a product stream, which will be containing very less amount of the pollutants and other things and they are getting removed. So, this is how a membrane process work. So, this is a schematic diagram of membrane process, how they work? So, this is there.

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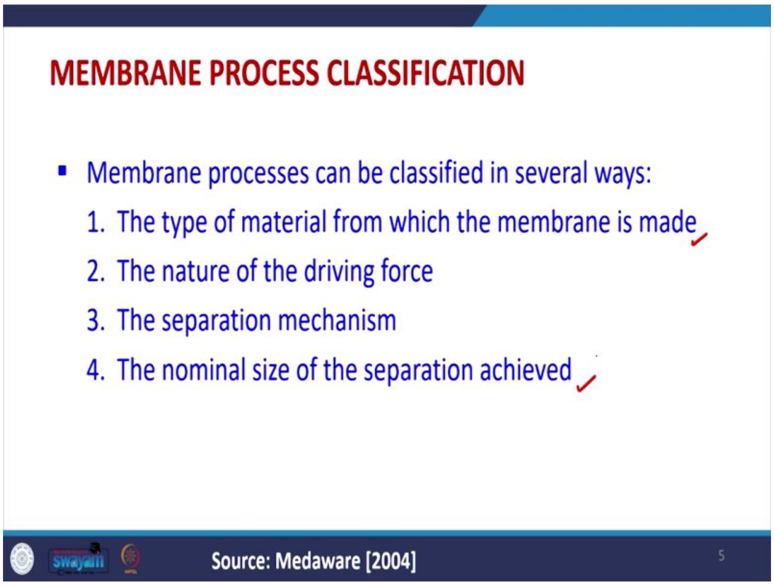

Now, membrane processes can be classified into via several ways. So, that will depend upon the type of material from which the membrane is made. So, this is one thing. So, that will depend upon that how much pressure has to be sustained, what type of constituents have to be removed. So, we can have some functionalities which are there on the membrane itself, that will help in the degrading some of the pollutants and filtering some of the pollutants.

So, this is there. So, depending upon that, this is we can classify membrane processes depending upon the type of material. Also, we can classify them depending upon the nature of driving force. So, whether it is pressure, whether it is electric, so, depending upon that we can vary the classify the membrane processes overall.

Then similarly, the separation mechanism whether it is filtration, whether it is reverse osmosis, or some other types of mechanism which may be combined together. So, depending upon the separation mechanism, we can classify the membrane processes. Then, what is the nominal size of the separation? So, that will depend upon the pore size, and what is the nominal size of the constituents that can be filtered out. So, depending upon that also we can classify the membrane processes into various types. So, this is possible.

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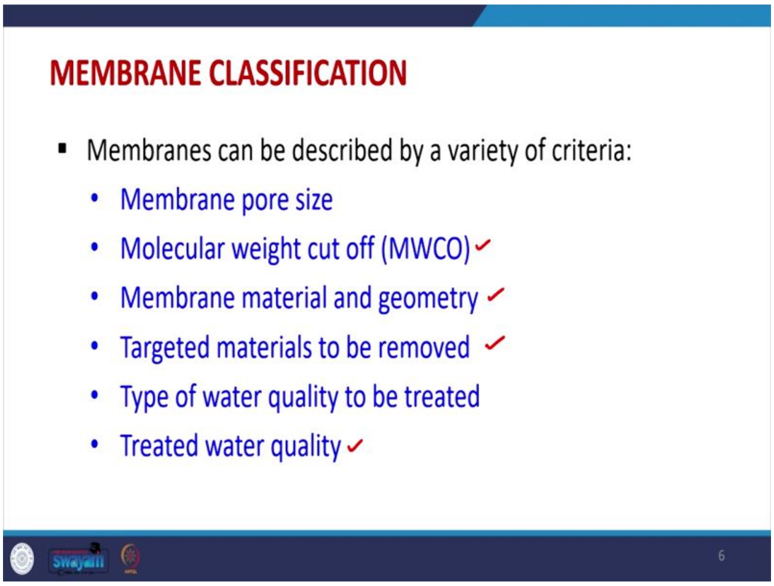

And membranes themselves can be described by a number of criteria. So, one thing is the classification of membrane processes, another is how membrane themselves can be classified, or described? So, for describing any membrane, we use a number of parameters, and those parameters include the membrane pore size, this is the most important criteria, that what is the size range under with different membrane processes are being operated.

So, we have microfiltration, we have ultrafiltration, we have nanofiltration. So, by the name itself you can understand microfiltration, ultrafiltration, and nanofiltration. So, what size range they are working. Similarly, what is the most molecular weight cut off by these membranes which is possible. So, through that also, we can describe a membrane itself. So, this is there. Similarly, membrane material and the geometry, this is another criteria under which the membranes can be classified.

Then what type of materials that we have to remove, whether we have to remove metallic material, we have to what is the size range in which materials have to be removed. So, all those become very important parameters. So, depending upon that, this is another criteria for membranes description. Type of water quality to be treated said that, water that we can treat in these membranes, so, that is also one of the criteria.

Then, what is the water quality which is desired? So, treated water quality is another parameter which is, which can be used to describe the membrane. So, membranes can be now we understand that membranes can be described by a number of parameters and these are listed here in this slide.

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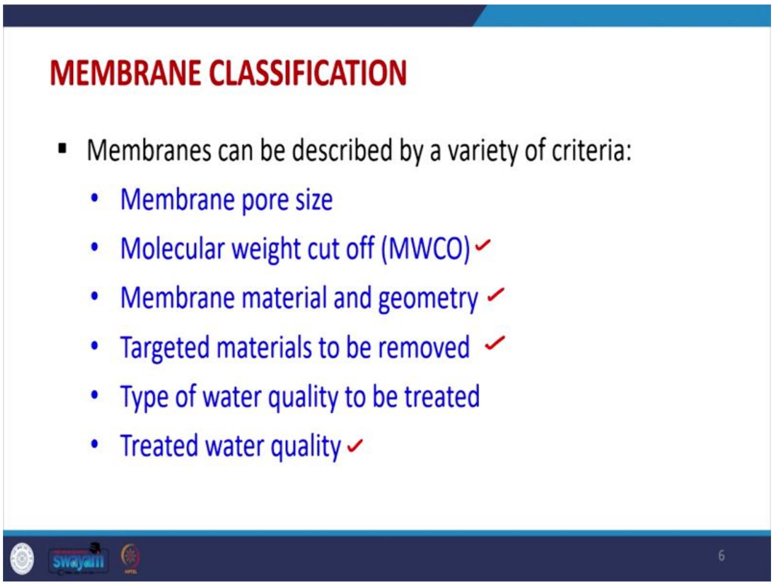

Going further, membrane processes can also be categorized broadly into whether they are pressure driven. So, this is very broad classification, whether they are pressure driven, or electrically driven processes. So, that is one thing, but we will be mostly discussing the pressure driven processes, because they are used in the water treatment more as compared to electric driven processes.

So, all of the water treatment processes are generally pressure driven processes. So, we will be only concentrating on the pressure driven membrane processes in these lectures that we are going to discuss all these things. As used in water treatment, membranes are classified into two broad categories. So, to separate ions from the solution, and to separate the suspended particles from the solution.

So, generally reverse osmosis and nanofiltration they can be used to separate the ions. Similarly, suspended particulates can be separated from the water using microfiltration and ultrafiltration. So, we have these four processes are generally considered to be the membrane processes which are used in the water, or wastewater treatment. So, depending upon the type of materials that have to be removed, so, these four processes can be used together.

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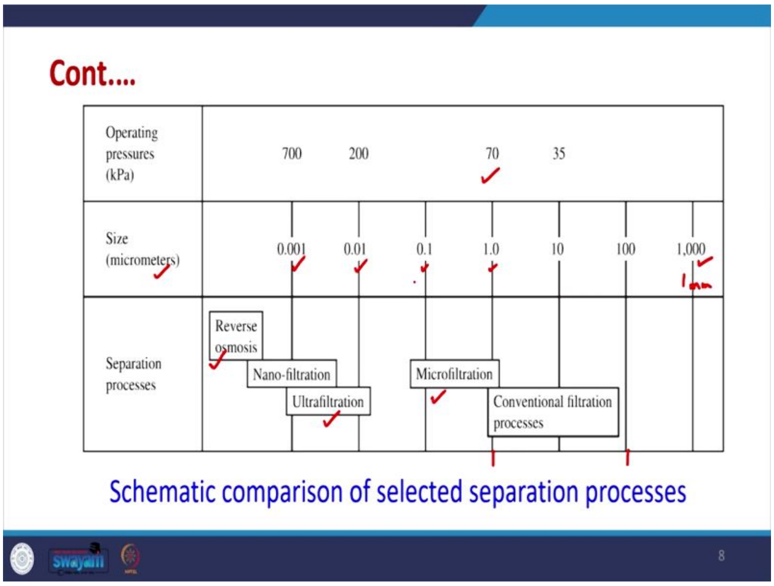

Now, these processes, they work for different operating pressure, different size of constituents they can remove, and so, they work in different pressure range and size range. Now, so, this is what is given here. So, we can see the size range in micrometres. So, as the size range increasing, so, you can see here, it is like one millimetre size here.

So, the conventional filtration processes are they are using sand, gravels, and all those things, they work in the range of 1 micrometre to 100 micrometre. So, these are the usual filtration process that we use in the treatment system. Now, if the size ranges below that and we want to remove much smaller size particles, suspended particles also. So, we can use microfiltration. So, microfiltration will work in the range of 0.1 to 1 micrometre.

Now, for using microfiltration, we use the pressure range in the range of like 70 kilo Pascal. So, 70 to 100 this will be the range under which we will be operating the microfiltration unit. Now, ultrafiltration units they work from 0.001 to 0.01 micrometre. So, this is the range, and they will be like 200 kilo Pascal will be the operating range typical pressure range under which they will work. So, they can work up to 0.1 micrometre also. So, that is why they are called ultrafiltration.

Then nanofiltration, they work in the much lower range and they work in the like nanometre range, and they are used for separating out nano size range constituents also. So, they can be used for removal of ions et cetera also. So, nanofiltration will work in that range so, they can be used for removal of ions et cetera. Similarly, if we have to go further down, we can use the reverse osmosis process, but the pressure range will be very high.

So, we can go up to thousand kilo Pascal also for reverse osmosis, but it will remove most of the ionic species out of the water also, and this will be in the ionic range we operate. So, reverse osmosis is very common in many industries for removal of various metals and other types of ions also from the water. So, this is these are the different schematic comparison of the membrane processes with respect to the size range under which they work, and what is the operating range under which they work for different pressure ranges. So, this is there.

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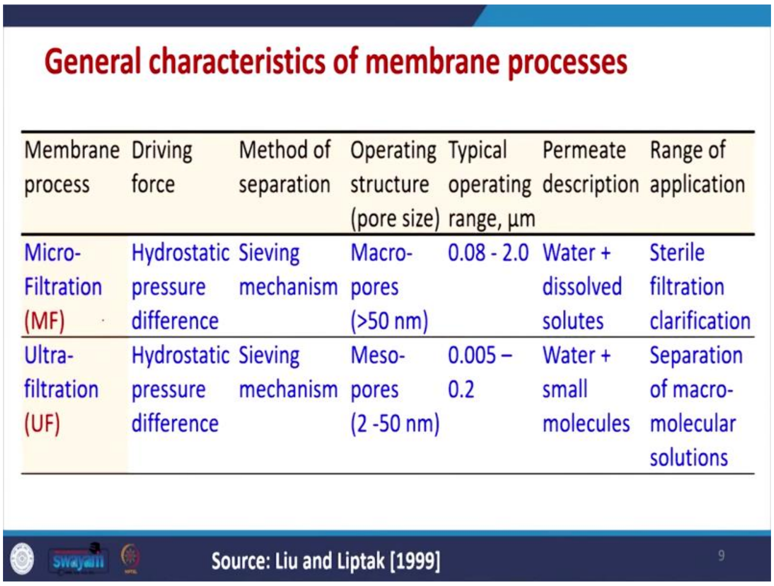

General characteristics of membrane processes

Membrane process	Driving force	Method of separation	Operating structure (pore size)	Typical operating range, μm	Permeate description	Range of application
Micro-Filtration (MF)	Hydrostatic pressure difference	Sieving mechanism	Macro-pores (>50 nm)	0.08 - 2.0	Water + dissolved solutes	Sterile filtration clarification
Ultra-filtration (UF)	Hydrostatic pressure difference	Sieving mechanism	Meso-pores (2 -50 nm)	0.005 – 0.2	Water + small molecules	Separation of macro-molecular solutions

Source: Liu and Liptak [1999]

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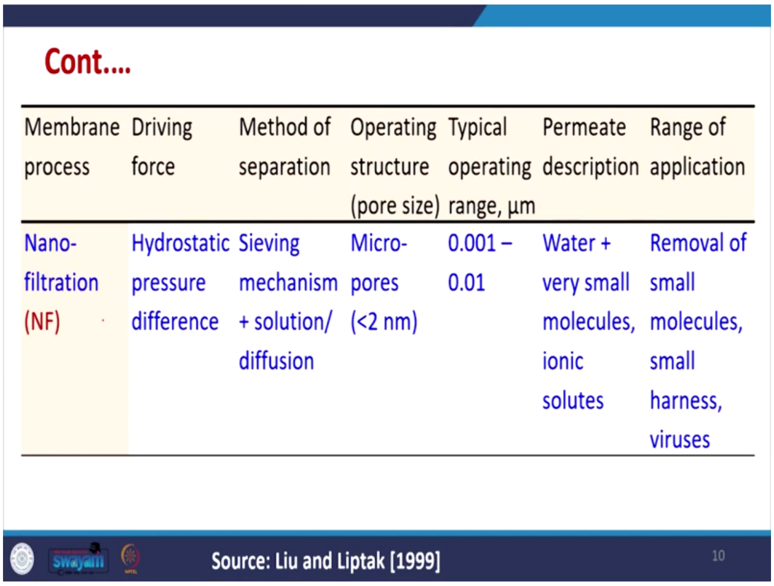

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Membrane process	Driving force	Method of separation	Operating structure (pore size)	Typical operating range, μm	Permeate description	Range of application
Nano-filtration (NF)	Hydrostatic pressure difference	Sieving mechanism + solution/ diffusion	Micro-pores (<2 nm)	0.001 – 0.01	Water + very small molecules, ionic solutes	Removal of small molecules, small harness, viruses

Source: Liu and Liptak [1999]

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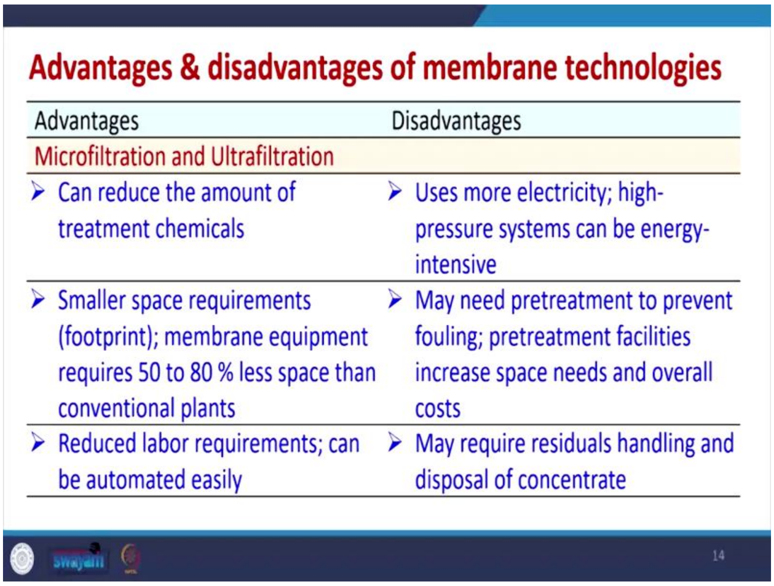
Membrane process	Driving force	Method of separation	Operating structure (pore size)	Typical operating range, µm	Permeate description	Range of application
Reverse osmosis (RO)	Hydrostatic pressure difference	Solution diffusion mechanism + exclusion	Dense (<2 nm)	0.0001 – 0.001	Water + small molecules	Separation of salts and micro-solutes from solutions

Cont....

Membrane process	Driving force	Method of separation	Operating structure (pore size)	Typical operating range, µm	Permeate description	Range of application
Dialysis	Concentration gradient	Diffusion in convection free layer	Meso-pores (2 -50 nm)	-	Water + ionic solutes	Separation of salts and micro-solutes from solutions

Cont....

Membrane process	Driving force	Method of separation	Operating structure (pore size)	Typical operating range, µm	Permeate description	Range of application
Electro-dialysis (ED)	Electrical potential gradient	Electrical charge of particle and size	Micro-pores (<2 nm)	-	-	Desalting of ionic solution



Advantages & disadvantages of membrane technologies

Advantages	Disadvantages
Microfiltration and Ultrafiltration	
➢ Can reduce the amount of treatment chemicals	➢ Uses more electricity; high-pressure systems can be energy-intensive
➢ Smaller space requirements (footprint); membrane equipment requires 50 to 80 % less space than conventional plants	➢ May need pretreatment to prevent fouling; pretreatment facilities increase space needs and overall costs
➢ Reduced labor requirements; can be automated easily	➢ May require residuals handling and disposal of concentrate

Now, general characteristics of different membrane processes, I will be discussing more in detail and these membrane processes include like microfiltration, ultrafiltration, nanofiltration, reverse osmosis, dialysis is also there, then electrodialysis. So, these we are going to try to compare all these processes. And now, when we are comparing these processes, there are different parameters under which they must be compared.

So, the most important parameters are like what is the operating range under which they are working, and what are the different types of materials they can remove, and what are the different types of characteristics of the membrane they use. So, we have three things broadly in this one thing is with respect to membrane, second thing is it what type of materials they can remove, and where they can be apply. And third thing is that what is the operating range or operating parameters under which they are working.

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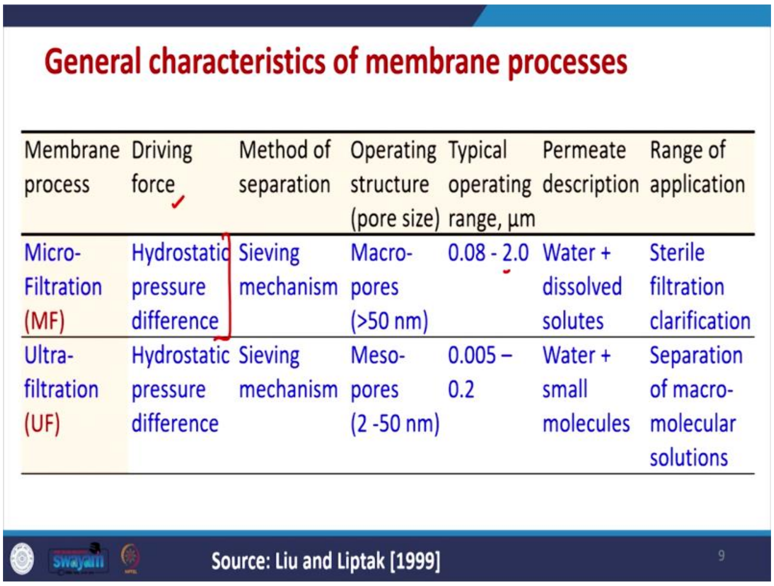

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Ultra-filtration (UF)	Hydrostatic pressure difference	Sieving mechanism	Meso-pores (2 -50 nm)	0.005 – 0.2	Water + small molecules	Separation of macro-molecular solutions

Source: Liu and Liptak [1999]

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Now, one of the important parameters is driving force and typical operating range with respect to size. So, this is their job. So, we will be only concentrating more on the hydrostatic pressure differences type of membrane processes. So, in most of our interest for water treatment, we will be using the hydrostatic pressure difference et cetera for separating different types of constituents.

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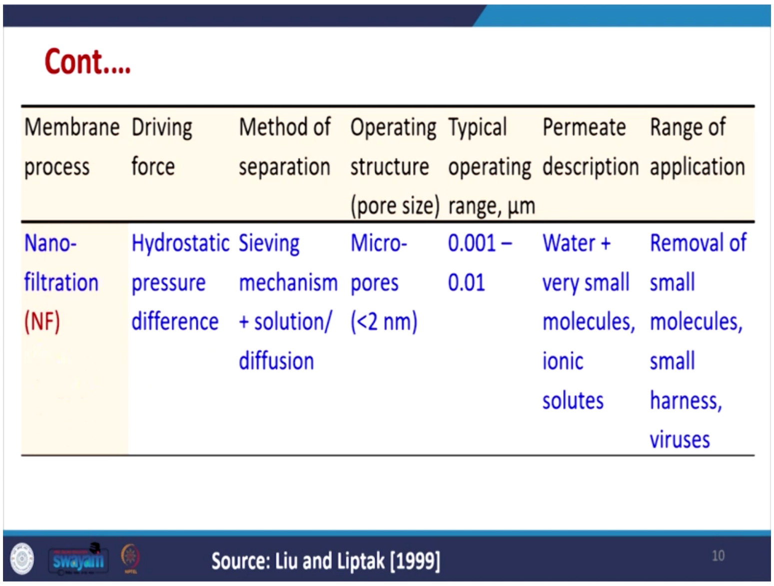

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Nano-filtration (NF)	Hydrostatic pressure difference	Sieving mechanism + solution/ diffusion	Micro-pores (<2 nm)	0.001 – 0.01	Water + very small molecules, ionic solutes	Removal of small molecules, small harness, viruses

Source: Liu and Liptak [1999]

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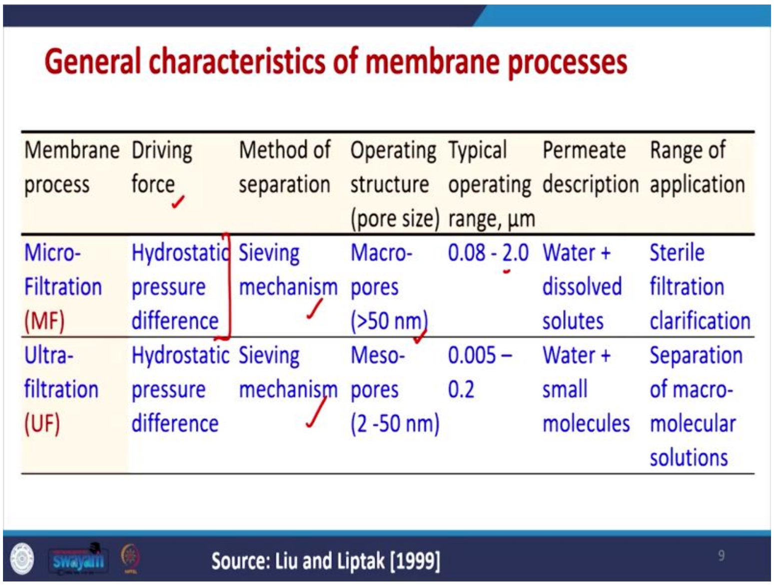

Now, out of these microfiltration, ultrafiltration, nanofiltration, they work on the sieving mechanism. So, all these three generally they will work on the sieving mechanism, we can see for nanofiltration also, but the operating structure or the pore size of the membrane is different for all these materials.

So, like some of the microfiltration in the microfiltration, we have micro pores, which are like more than 50 nanometre and under this condition, they are able to remove the constituents in the size range of 0.08 to 2 micrometre. So, this way we will be getting what we will get in the permeate is the water plus some amount of dissolved solutes. And this method microfiltration can be used for filtration, for clarification et cetera.

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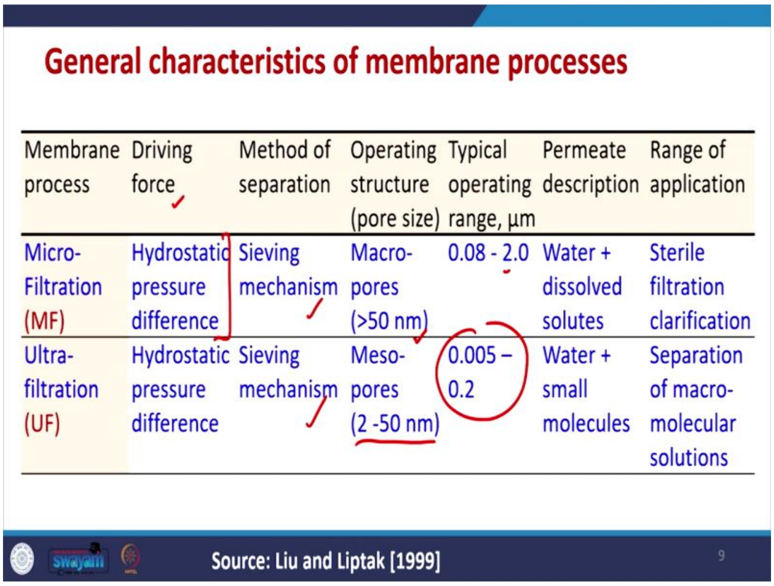

Then we have ultrafiltration again the hydrostatic pressure driven force membrane process it is, it also works on the sieving mechanism, but it is a pore size range is different. So, they will be working in the meso-pore range. So, it will be from 2 to 15 nanometre, and they can remove constituents in the size range of 0.005 to 0.2 micrometre.

So, this way we are able to remove this size range of constituents. So, what we get is that water with molecules smaller than the size range. So, permeate will be containing some small molecule certainly. So, and this method ultrafiltration can be used for separation of macro molecular solutions et cetera, this is there.

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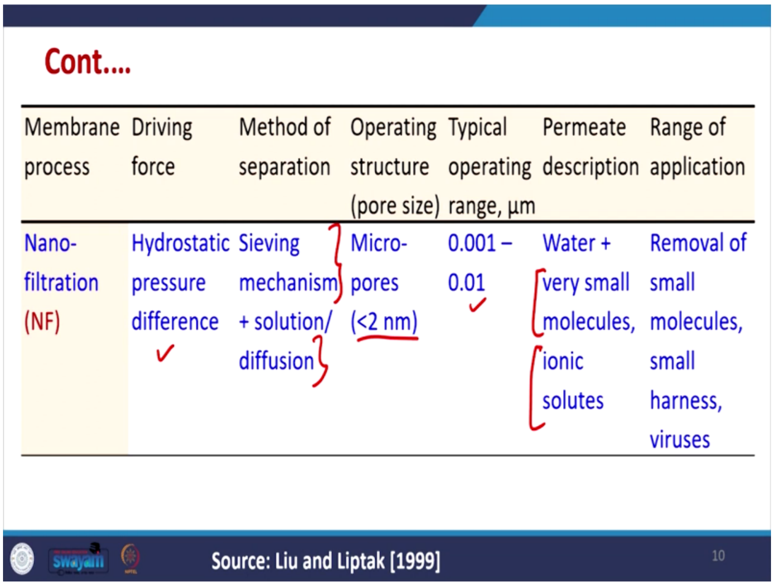

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Now, going further we have nanofiltration, another membrane process. So, for this process also we have pressure difference is the important driving force which is used. Now, again this process because the size has decreased. So, we have sieving mechanism certainly, but we have diffusion also one of the mechanism which comes into picture as a method of separation for these processes.

Now, since the sizes decrease so they work in the micro-pores range, and less than 2 nanometre, and under this range, they are able to remove the constituents in the size range of 0.001 to 0.01 micrometre. So, they are able to do much smaller size materials as well. And thus the permeate that we get is generally containing water will certainly be there, very small size molecules plus some ionic solutes will also be present in the water if nanofiltration is used for as a removal process. This can be used for removal of small molecules many water containing viruses et cetera also it can be used for filtering those materials.

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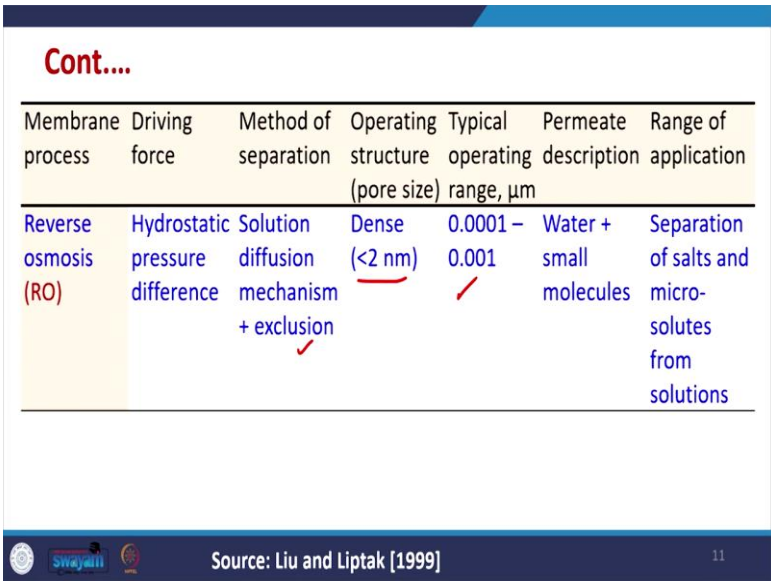

Going further, reverse osmosis is one of the very, very common technique and which is used virtually in the all the small units, bigger units et cetera. It is very common in many industries where like zero liquid discharge et cetera has to be done. And reverse osmosis is very, very common, though it is a energy intensive process and we are but we are able to remove most of the material using this process.

The one thing is this, the again the pressure different is used osmotic pressure difference. And then, solution diffusion mechanism works, plus exclusion because the size range is smaller, they again have the size range is less than 2 nanometre and they are able to but they are able to remove one unit more lesser size particles also.

So, they work in the from 0.001, or 0.1 nanometre to like 1 nanometre or more. So, this is the range under which they work, and they are able to remove all the constituents in this size range. So, the permeate that we will be getting will be containing water, plus very, very small size molecules. And this RO is used for separation of salts, micro solutes et cetera from solutions, and this is very common technique which is used virtually everywhere.

So, ultrafiltration, nanofiltration, or microfiltration that will depend upon the what size range of materials that we have to remove, what is the concentration of those materials in the water and plus, what are the further treatment that we have to do. So, if you have a zero liquid discharge unit that is there like pulp and paper industry, or any other industry, where the rule is that we should have no discharge.

So, under that condition, we have to virtuality treat all the water, then, all these different membrane separation processes may be used and thus we concentrated the pollutant from very dilute concentration to very high concentration, thus reducing the amount of water that has to be evaporated in multiple effective operator.

And all these processes, membrane processes, through these processes we are able to get water which is recycled back into the system also for further use. So, we do not require very high amount of water in the process, we most often we will recycle more than 95 percent or more of the water in the system itself. and the small amount of reject water that we get that has to be treated further or evaporated further.

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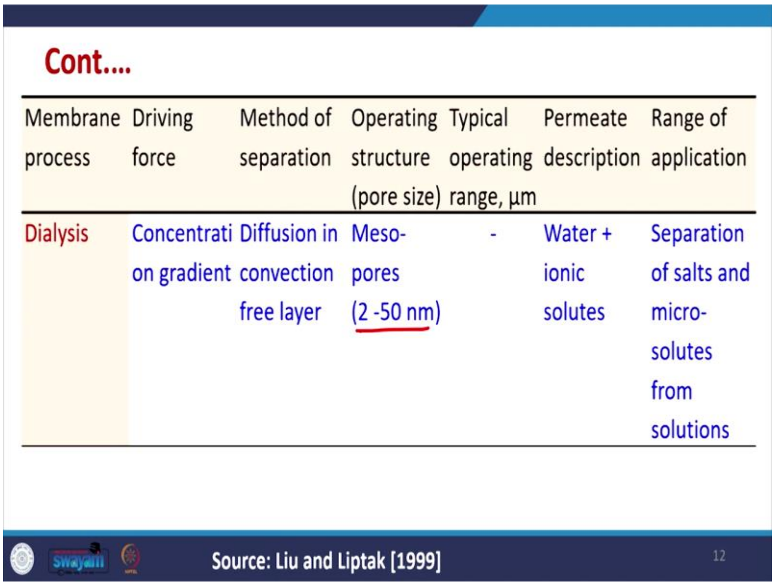

Membrane process	Driving force	Method of separation	Operating structure (pore size)	Typical operating range, μm	Permeate description	Range of application
Dialysis	Concentration gradient	Diffusion in convection free layer	Meso-pores (2 -50 nm)	-	Water + ionic solutes	Separation of salts and micro-solutes from solutions

Now, dialysis is another membrane process in which the concentration gradient is the driving force. And in this case that diffusion in the convection free layer which is just adjacent to the membrane is this method of separation, and it works in the range of 2 to 50 nanometre, and they are able to remove different types of, different size range of the constituents and the permeate that we get is water plus ionic solutes and they are able to they are used for removal of salts, micro solute et cetera from the solution.

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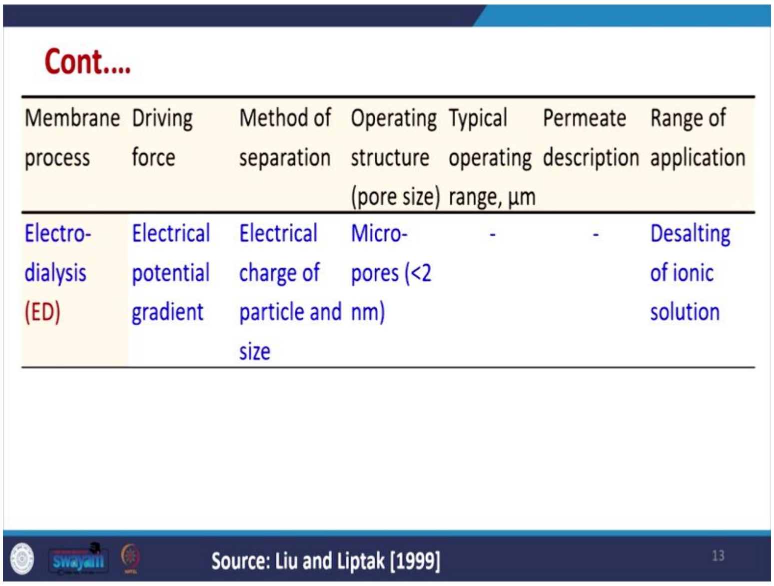

Similarly, electrodialysis is also used, where electrical potential gradient is used, then electric charged particle and the size of the particle both become important parameters as a method of separation. The size rage is in the micro-porous range. less than 2 nanometre itself, and this is used most commonly in the desalting of ionic solution. Electrodialysis is also used in the various biological treatment or separation for human body as well. So, like for blood cleaning et cetera. So, this is very common technique in the biomedical field. So, electrodialysis is used, but it is not common in water or wastewater treatment.

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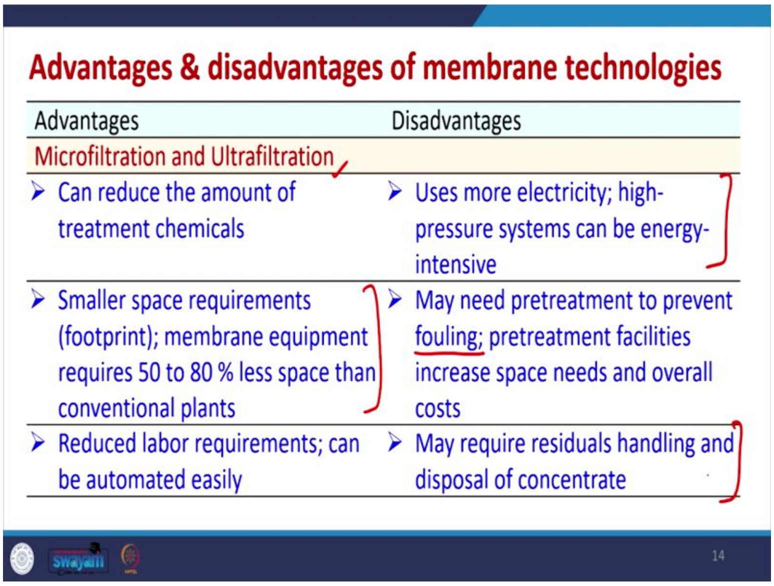

Now, we will try to understand the advantages and disadvantages are different membrane technologies. So, for microfiltration and ultrafiltration the advantages and disadvantages are listed here. So, the advantage is that they are able to reduce the amount of treatment chemicals because they are able to separate out many of the constituents beforehand, and but they use more electricity, and high pressure driven systems can be energy intensive also, and this disadvantage is for all the membrane separation processor, so, this is there.

They have much smaller space requirement as compared to other filtration processes. And but, as the membrane equipments require 50 to 80 percent less space than the conventional filtration unit, but they may need pre-treatment to prevent fouling, because if the concentration of the constituents or the pollutants in the water is very high that means the fouling will be high for these microfiltration and ultrafiltration unit.

So, when we may have to pre-treat the water before actually using the microfiltration and ultrafiltration unit. So, this is one of the problems that fouling is one of the problem, then pre-treatment facilities increase the space required. So, we have to cross-check that whether certainly we are saving on the space or not, and some similarly, the overall cost will also increase because we will be requiring pre-treatment and additional space for the pre-treatment as well.

Now, in this microfiltration and ultrafiltration, the labour requirements are much lower and these systems can be automated very easily. So, this is there, but in these systems again we have a reject et cetera and these residuals they have to be handled and since they are concentrated the disposal of the concentrated solutions is an issue and this is common for this problem is common for other membrane separation processes as well. So, in all the membrane separation processes reject treatment or how to manage the reject is the problem.

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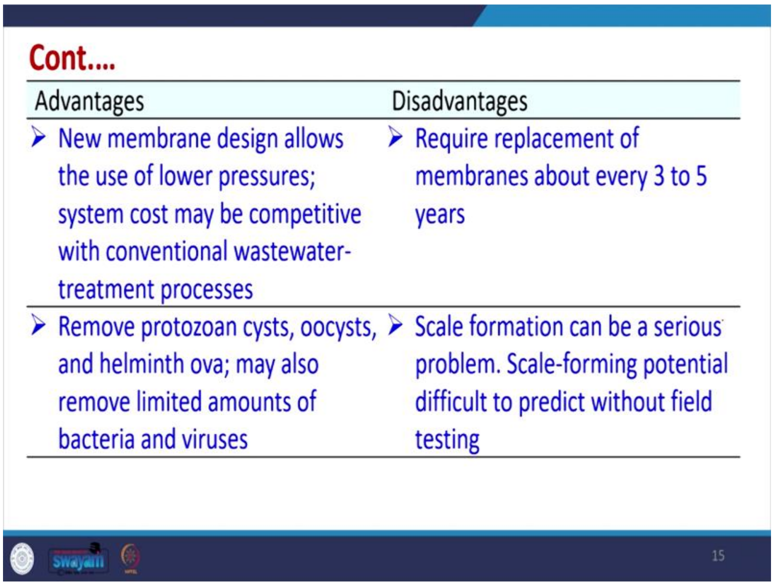

Now, in the microfiltration and ultrafiltration, new membrane design allows the use of lower pressures and system cost may be competitive with the conventional wastewater treatment processes. So, we can if we can design properly, they can be competitive to the conventional wastewater treatment processes also, but the replacement of membranes after a certain number of year, this is the disadvantage and that we have to cross-check with respect to optimization, cost optimization, whether they can be used or not.

They can be used for removal of various other types of constituents like protozoan, oocyst, helminth et cetera. And they are they can be used for removal of some amount of bacteria viruses, but not very common. For that we have to go for nanofiltration, again the scale formation can be a serious problem with all these microfiltration and ultrafiltration unit. So, we have to cross-check whether the scale formation or fouling is not occurring.

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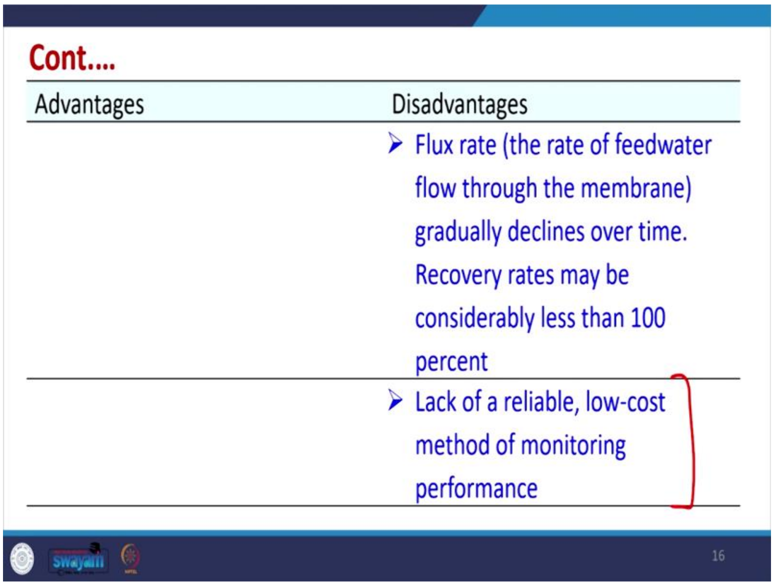

Now, some other disadvantages is that the flux rate the rate of feed water that flows through the membrane, that declines gradually with time, and that happens because we have to a cake formation will start occurring on the membrane itself, and because of that cake formation, that cake will also offer resistance to the flow of the water.

And so, because of that, there will always be a gradual decline in the flux. So, and the recovery rate may become very less with time. So, and with respect to performance also sometimes we have to cross-check. So, cost wise and other things as some of the issues may happen. So, certainly it is a costlier process as compared to the conventional filtration process. So, these are the disadvantages of this system.

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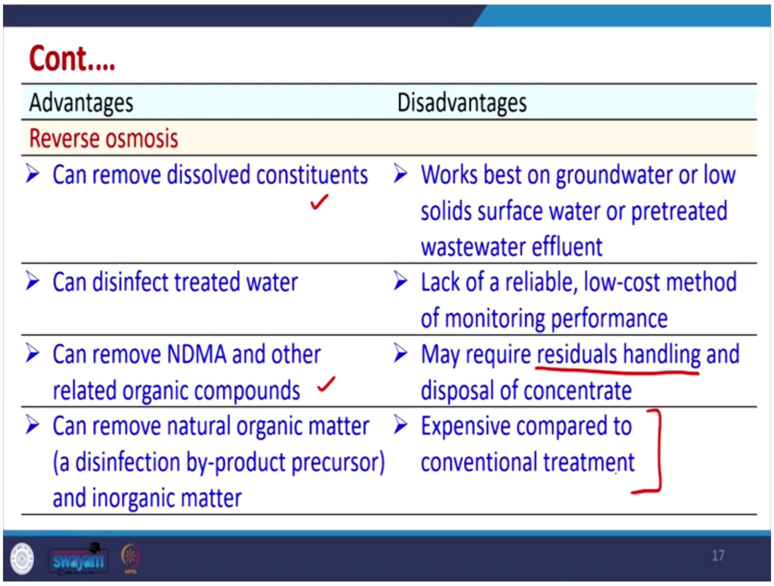

Now, one further we have reverse osmosis process also which is very commonly used in the treatment in the industry as well as in the household water treatment units which are there. Now, these RO units, they are able to remove the dissolved constituents. So, in this way they are very, they can be used very well to balance the TDS that how much amount of TDS we have to see in the water.

So, we can remove the dissolved constituents, or we can decrease the TDS also in the water. So, RO in the residences is most commonly used for decreasing that TDS. So, this is one good advantage of RO unit, they can be used to disinfect treated water also because they can be used to remove some of the pathogens et cetera also, viruses bacteria.

They can remove NDMA and other organic compounds also, disinfectant materials et cetera also, and they can be used to remove the natural organic material also and which can be a disinfectant by-product precursor. So, this is so, using the membrane processes followed by some advanced oxidation processes are disinfection processes is good because we are able to remove the natural organic material.

So, if we are using any chlorinated compounds et cetera for disinfection, so, that issue will be solved because we will not be getting that much disinfectant by-product. So, that is there. Now, disadvantages include works best for the groundwater, or low solid surface water, or pretreated wastewater effluent So, if you directly use the RO unit, the amount of reject will be high the failing conditions et cetera will be very, very enormous and continuously running the RO unit will be a challenge.

RO units have a like costlier processes as compared to other treatment processes. So, one of the important disadvantage is that they require a lot of money for not only capital costs, but as a operating cost as well. And the main issue is that we have the how to handle the reject or the residuals that are there and disposal of the concentrate. So, in many industries actually, they use evaporation for disposing the concentrate.

So, thus they evaporate all the remaining water and the solid is the only thing that remains and this they give that solid residual to any agency which is used for landfilling, et cetera. So, they have all those facilities, or ultimately the solid will go there, but they this way they are able to reduce the amount of residuals, but using a multiple effective operator that requires lot of energy. So, that becomes a highly energy intensive process which is not desirable by any industry or otherwise.

So, the residual handling and disposal of concentrate is important issue with respect to all the RO units and certainly this is very expensive as compared to the conventional treatment method. So, these are the various RO type of systems. So, in today's lecture, we have try to understand that okay, what are the basic membrane processes, so, in a membrane processes, we have a feed stream and a semipermeable membrane, and semipermeable membrane allows some of the constituents to pass through it.

So, it will allow the water to pass through it. So, all the constituents that have to be filtered out, they remain on the other side and they are generated as the reject or the residuals and we get a permeate stream which is free of the desired constituents. And so, thus we are able to treat the water or wastewater.

Now, there are broadly four type of membrane processes which are used in the water treatment and these include microfiltration, ultrafiltration, nanofiltration and reverse osmosis. And they are the membranes used in all these systems they have different size range, they have they are generally pressure driven forces, all the driving forces are pressure driven, and they are able to remove different types of constituents from the water. So, through this we now end today's lecture and we will continue understanding the membrane processes for wastewater treatment in the next lecture and further. Thank you.