**Biological Process Design for Wastewater Treatment**
**Professor Vimal Chandra Srivastava**
**Department of Chemical Engineering**
**Indian Institute of Technology Roorkee**
**Lecture 29**
**Advanced Biological Wastewater Treatment: Membrane Bioreactors**

Welcome everyone in this NPTEL online certification course on Biological Process Design for Wastewater Treatment. So, in the previous lecture, we started studying regarding the Advanced Biological Wastewater Treatment Systems. And in the previous lecture we studied regarding the fluidized bed bio reactors. So, continuing further Today we will be learning regarding the membrane bio reactors, which are nowadays used in the biological wastewater treatment.

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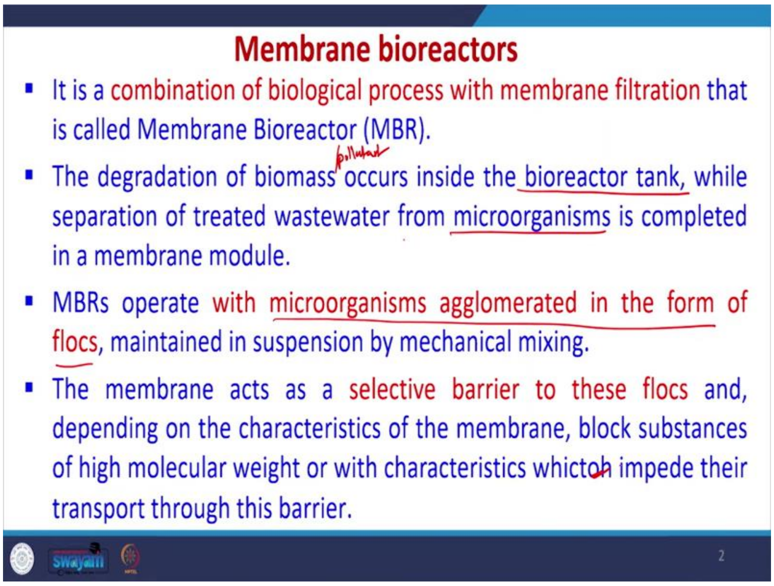


So, membrane bioreactors certainly have membrane which is used in combination with the biological processes. So, membrane bioreactors used a combination of biological processes along with the membrane filtration that is, overall together called as membrane bioreactor. So, in this case, actually the degradation of any solid material or the biomass or of that of the pollutant occurs inside the bio reactor tank.

So, we have all the COD etc. Gets removed in the biological reactor after that separation of the treated wastewater from the microorganisms because the microorganisms are present and biomass is there and the pollutant occurs inside the bioreactor. So, we have to separate them. So, there is option we can use the settling tank or we can use the membrane bioreactor. So, in this case, the separation of the treated wastewater from microorganisms it is done in the membrane module.

So, MBRs operate with microorganisms agglomerated in the form of flocs and they are maintained in suspension by mechanical mixing the membranes act as a selective barrier to these flocs. And depending upon the characteristic of the membrane, they block substances of higher molecular weight are with characteristics which impede their transport through these barriers that means. We have two sections in a way.

One section in which the treatment of the wastewater happens, where the pollutants are biodegrade in presence of microorganism. So, this is step one, after that the microorganism treated wastewater go to the step two, where the separation of the microorganisms occurs via membrane. So, this is the membrane bioreactor.

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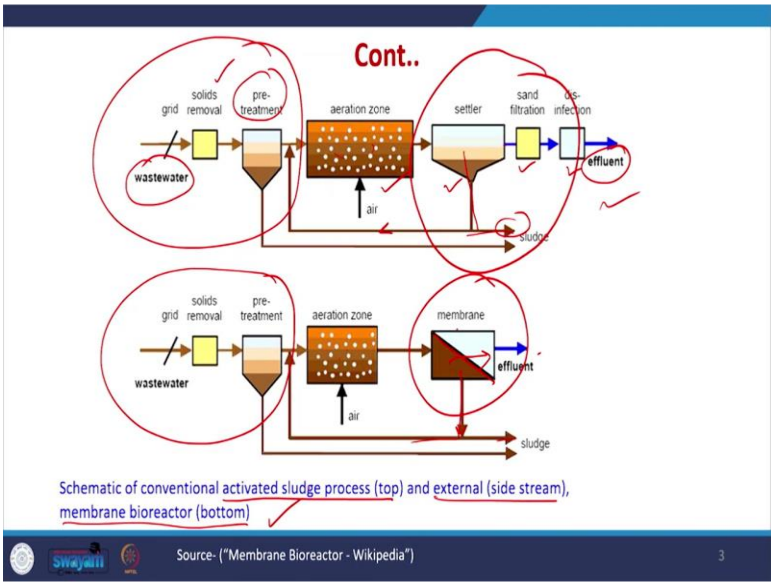


So, we can see here that traditional wastewater treatment using an activated sludge process. So, we have activated sludge process in which the wastewater is coming, the solid removal happening in the physicochemical treatment then some pretreatment happening after that, in the activated sludge, we have a air which is there and the treatment happening, after that we use the settler or the clarification unit where the settling happens some of the sludge is recycled back or other is wasted.

Now, after this the treated effluent which is coming out is further sand filter and disinfected before effluent goes out in place of that in the membrane bioreactor. Here the case of external side stream membrane bioreactor is given there could be possibility of this membrane give inside also. So, here again up to this section, the unit the treatment unit is common with the traditional activated sludge process.

Then, we have aeration zone also which is common as compared to earlier. Now, after treatment in place of clarifier and filtration, we have a membrane system, where a membrane module is there, which allows only effluent, treated effluent are clarified effluent or effluent without any solid material and biomass etc., to go out this biomass, our microorganism or sludge is recycled and some of the sludge is wasted also. So, this we are replacing this particular thing with membrane system in a membrane bioreactor. So, this is the membrane bioreactor.

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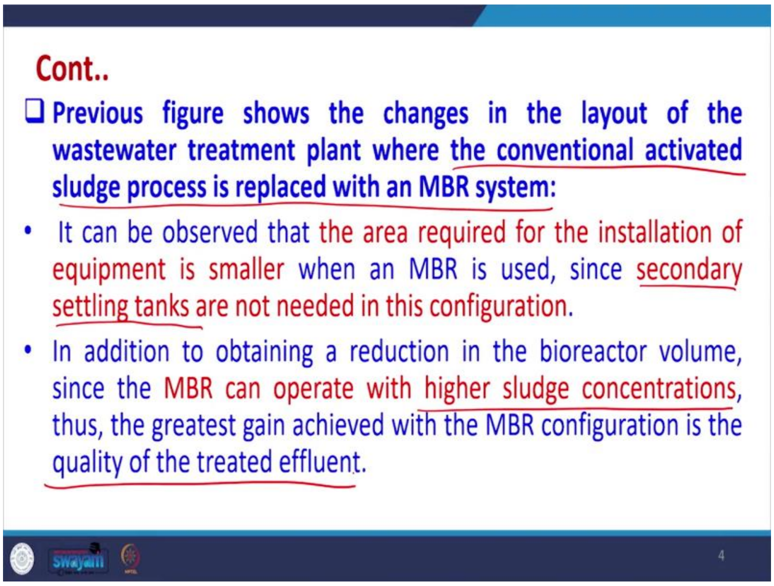


Now, in the previous figure, we can see that you change in the layout of the wastewater treatment plant, where the conventional activated sludge process is replaced with an MBR system, it can be observed that area required for the installation of equipment may be smaller when the MBR is used, since, we are not using any secondary settling tank in the MBR system, so, that means, there is a configurational changes happening and actually the area required will be smaller in the MBR system.

In addition to obtaining a reduction in the bioreactor volume, because of this, the MBR can operate with a higher sludge concentration. So, that means, we can operate with higher sludge concentration, bioreactor volume will be decreased and also the overall quality of the treated effluent is much better in an MBR system as compared to in the activated sludge system. So, these are the advantages that we gain with the MBR system.

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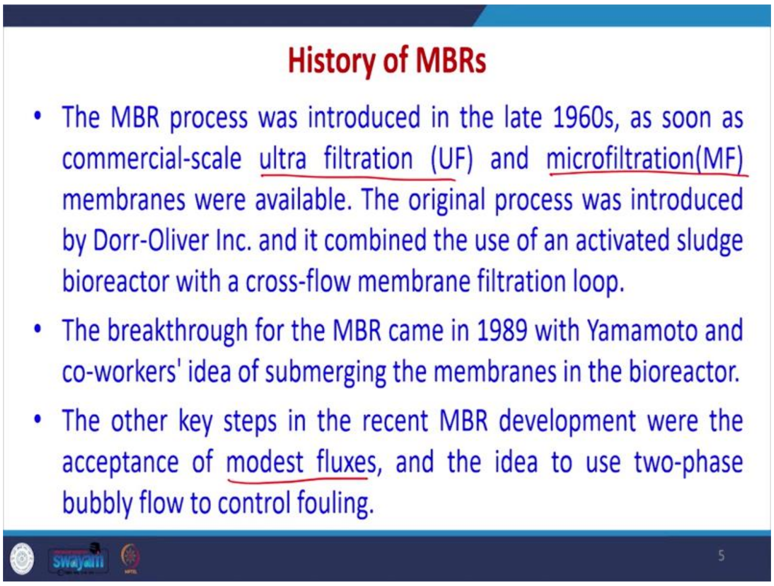


Now, the MBR system was developed in 1960s. As soon as the ultra-filtration and micro filtration membranes were developed or were commercially available, the original process was introduced by Dorr and Oliver however, it combined the use of and activities sludge bioreactor with cross flow membrane filtration loop. The breakthrough of MBR system happened in 1989 with Yamamoto and co-worker's idea of submerging the membrane inside the reactor itself. So, this happened earlier.

The other key aspects in the recent MBR development were the acceptance of the modest fluxes and the idea to use two phase bubbly flow to counter fouling also, because in the membrane in bed reactors, the membrane here the fouling is very important parameter which we will be discussing later on.

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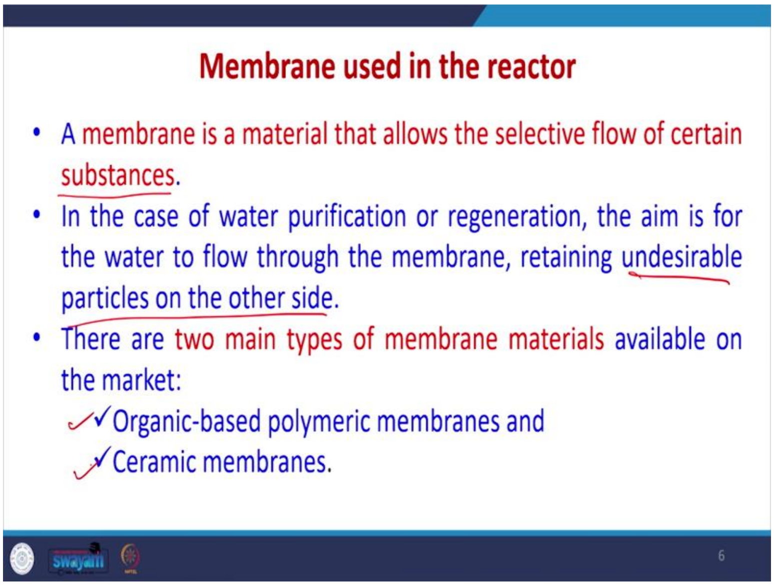


So, membranes used in the reactor which type of membrane has to be used, what material sector so, a membrane is a material that allows the selective flow of certain substance. So, this is the classic definition of membrane in the case of water purification our regeneration, the aim is for the water to flow through the membrane, but retained undesirable particles on the other side itself.

So, generally, two types of membrane materials are used in the membrane bioreactor, and these are organic based polymeric membranes. So, this is there, then we have ceramic membranes which are used. So, broadly two types of membrane materials are used in the membrane bioreactor.

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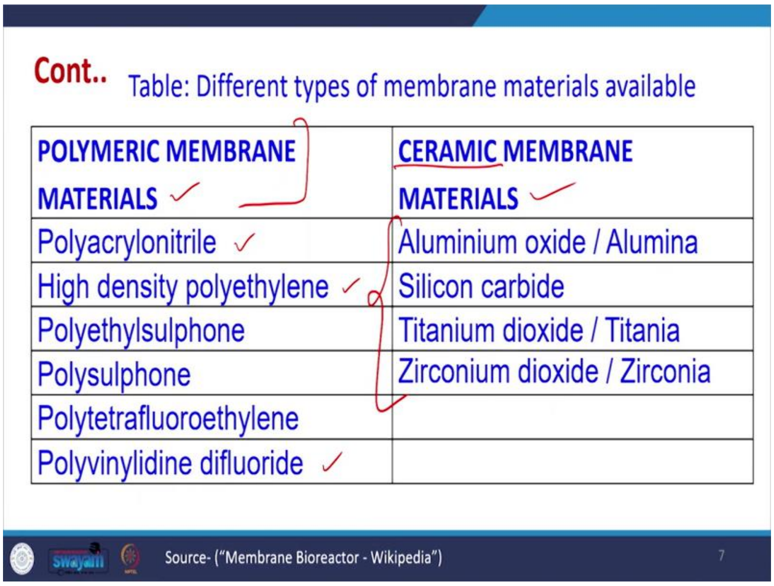

Now, these polymeric membrane materials and ceramic membrane materials, the different types which are used include holy Polyacrylonitrile, High density Polyethysulphone, Polysulphone, Polytetrafluoroethylene, Polyvinylidine difluoride are used as polymeric membrane materials in the membrane bioreactor in case ceramic base materials are used, then the commonly used the ceramic base materials include Aluminium oxide or Alumina, Silicon carbide, Titanium dioxide or Titania and similarly, Zirconium dioxide or Zirconia. So, these are the commonly used ceramic membrane materials in the membrane bioreactor. So, certainly they must be having some comparison.

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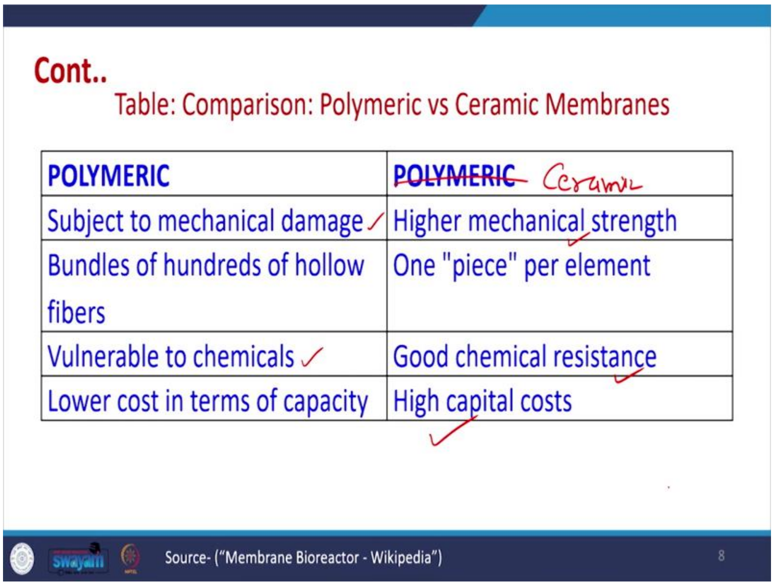


| POLYMERIC | ~~POLYMERIC~~ Ceramic |
|---|---|
| Subject to mechanical damage | Higher mechanical strength |
| Bundles of hundreds of hollow fibers | One "piece" per element |
| Vulnerable to chemicals | Good chemical resistance |
| Lower cost in terms of capacity | High capital costs |

So, polymeric materials they are subjected to mechanical damage. So, there is a possibility that if some very high flow rate is there etc. Then some mechanical damage may happen also bundles of hundreds of hollow fibers are generally available, they are also vulnerable to chemicals also it is possible that if the pH is low, then these polymeric materials may get affected too that means, they are mechanical as well as chemical stability is lower as compared to ceramic sorry, this is ceramic membranes.

Now, but they are lower cost in terms of a capacity as compared to ceramic membrane ceramic membranes are higher cost, but they have very good chemical resistance and they have a higher mechanical strength. And also they may be available in one piece per element also as compared to polymeric materials which are available in bundles of hundreds of hollow fibers. So, these are the certain comparison certain advantages and disadvantages. Ceramic membranes are better, but they have higher capital cost as compared to polymeric membranes.

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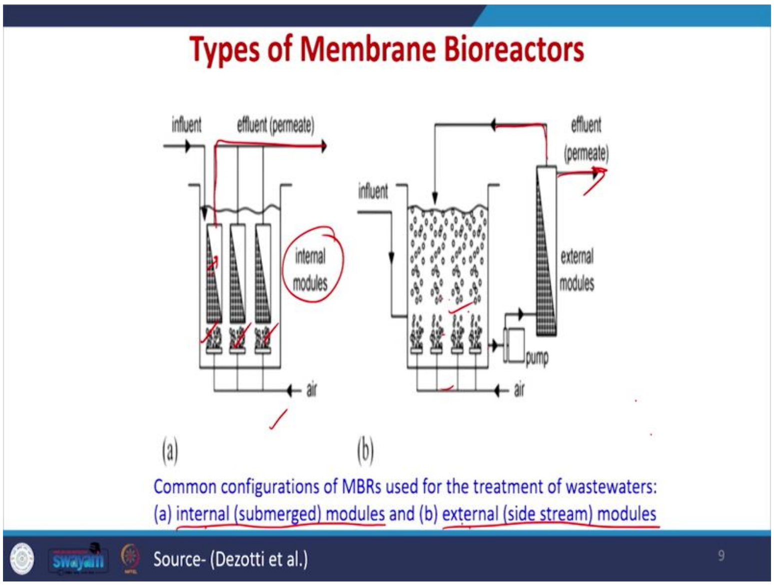


Now, types of membrane bioreactor, so, how the membrane bioreactors may be there, so, we earlier took the advantage of external side stream module, so, but there is a possibility of internal submerged modules also. So, in the in case of internal submerged modules, the modules are submerged inside the biological treatment unit itself. So, that means, we have influent which is coming this in the biological treatment system here actually this system of module is such that, that it will allow only the water to go inside this and this water will be taken outside the permeate will be effluent treated effluent will be taken out.

So, there are different two three modules or many internal modules are kept inside the wastewater treatment or the biological water treatment section itself the activated sludge process. In the second case, the effluent goes inside in the activated sludge process, where the treatment happens. And after the treatment, the water along with the microorganisms is treated, taken to the external module.

Where the separation of the microorganism's sludge, etc., happens that treated effluent depending upon the requirement may be recycled and the permeate is taken out. The majority of effluent will be taken out and further be treated depending upon the requirement or it may be discharged as such. So, this is the difference. So, we have to membrane bioreactor types, one is the internal and other is the external one.

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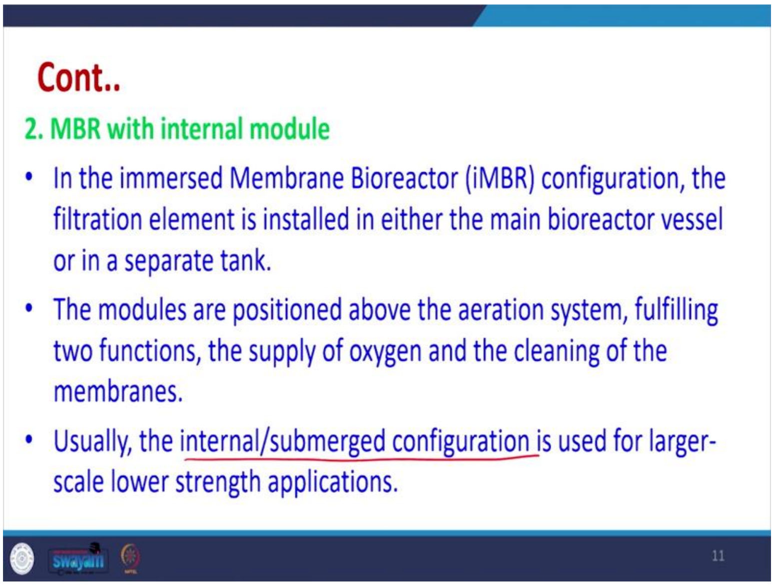


Now, membrane with the external module, the filtration modules are outside that aerobic tank hence the name side stream configuration, the biomass is either pumped directly through the several membranes modules in series and when to the bioreactor or the biomass is pumped to the bank of models from this the second pump is recirculate the biomass through the modules in series usually the external inside the steam configuration is used for small scale high strength applications.

So, where the wastewater characteristic the COD is very high for that case, this module is used now MBR with internal module in the immerged membrane bioreactor configuration the filtration element is installed in either the main by reactor vessel or in the separation tank. The modules are positioned above the aeration system fulfilling the two functions, the supply of oxygen and the cleaning of the membrane also, usually the internal and submerged configuration use for larger scale.

But low strength application so, where are the wastewater characteristics, the COD, etc., is low. Now, the fouling in MBRs is one of the most critical factor which affects the membrane bioreactor performance.

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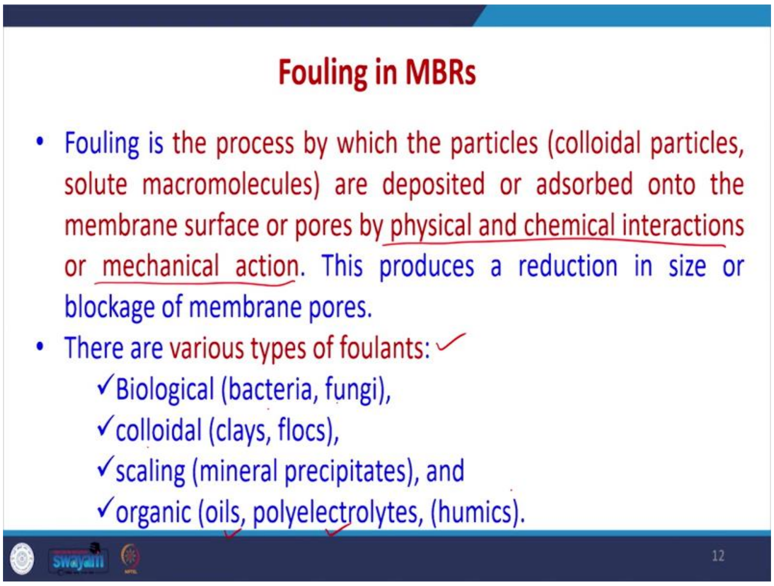


So, Fouling is the process by which the particles that colloidal particles the solute macro molecules are deposited are absorbed on the membrane surface or pores by physical or chemical interactions or by mechanical action. So, in any case if the particles maybe colloidal particles are some micro molecules get deposited on the membrane module, then it affects the performance of the MBRs. Now, there are various types of foulants which are possible fun is biological. So, like bacteria fungi then we may have colloidal particles like clays, flocs, etc. getting deposited, then scaling the mineral precipitates, they may also get deposited. Similarly, organic foulant may also be there like oils, poly electrolyte humics etc. So, all these may get deposited on the membrane module and does foul the MBR.

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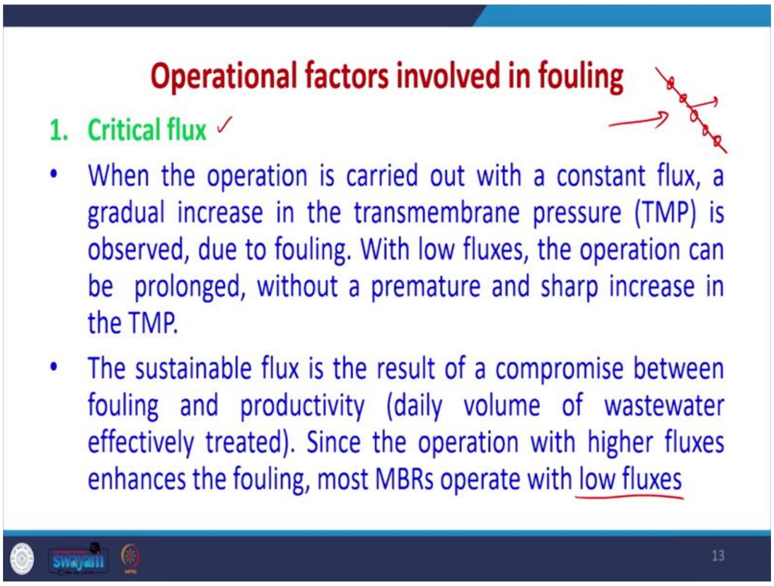

Now, operating factors involved in the fouling. So, critical flux when the operation is carried out with a constant flux a gradual increase in the transmembrane pressure is absorbed due to fouling. So, that is when we have a module now, the module is having certain pores. Now, when these pores are getting blocked actually the pressure which is required to maintain the same flow rate across the membrane, so, that will increase so, that means the at TMP that transmembrane pressure will be increased for maintaining a constant flux, this is what happens because of the fouling the sustainable flux is the result of the compromise between the fouling and productivity.

So, since the operation with higher fluxes enhances the fouling most MBRs operate with the low fluxes. So, lower the constant flow rate lower are the chances of fouling and we can maintain that flux. So, this critical flux is important, where the fouling is minimal, and that critical flux is always maintained for longer duration of treatment.

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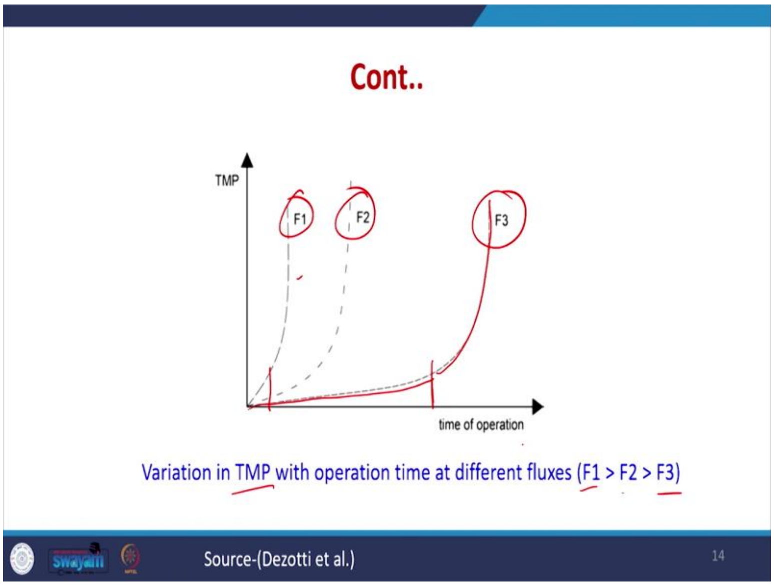


So, this is how variation in the transmembrane pressure with operation time at different fluxes. So, if flux we can see F1 is fluxes higher than F2 and this F3. So, we can see the with lower flow rate, the time of operation is higher and the pressure drop only after a certain time it will certainly increase whereas, when the flux is very high, this time of operation is much lower as compared to when the flow rate is less. So, we had to critically decide at what fluxes we have to operate the system. So, this is a critical factor.

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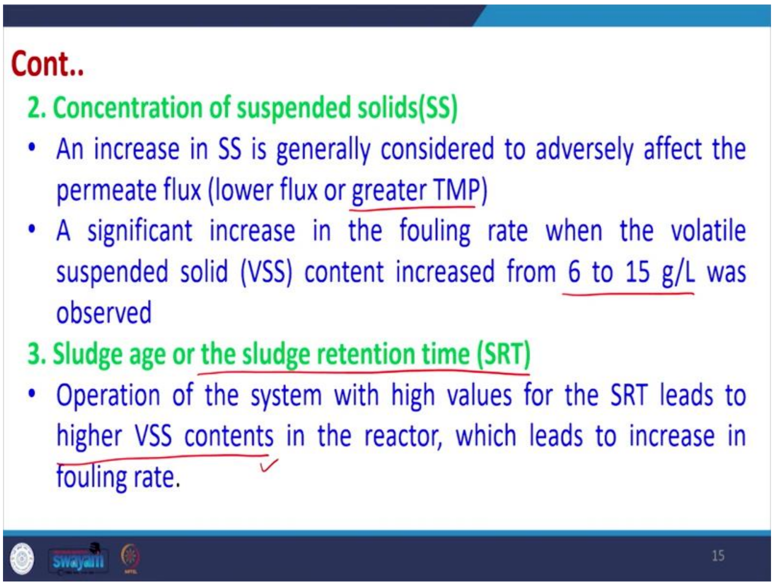


Similarly, concentration of suspended solids, an increase in suspended solid is generally considered to adversely affect the permeate flux are lower flux and greater TMP will be observed in this case. So, we desired the suspended solid to be minimum present in the water, a significant increase in the fouling rate happens when the volatile suspended solid is increased from 6 to 10 gram per liter.

So, this increase in the VSS also increases the fouling rate. So, this is again then the sludge age or the sludge retention time. So, this is very important parameter for treatment of wastewater in the activated sludge system. Now, operation of the system with higher values of SRT leads to higher VSS content. So, that means, though the sludge age is important factor and sludge age will affect the treatment efficiency.

However, if the sledge age is higher, it will increase the VSS content in the reactor and if the VSS content increases, the chances of fouling also increase. So, we have to suitably decide in the membrane bioreactor that at what sludge age we have to operate the bioreactor so, that the membrane module can work efficiently and the minimum fouling happens.

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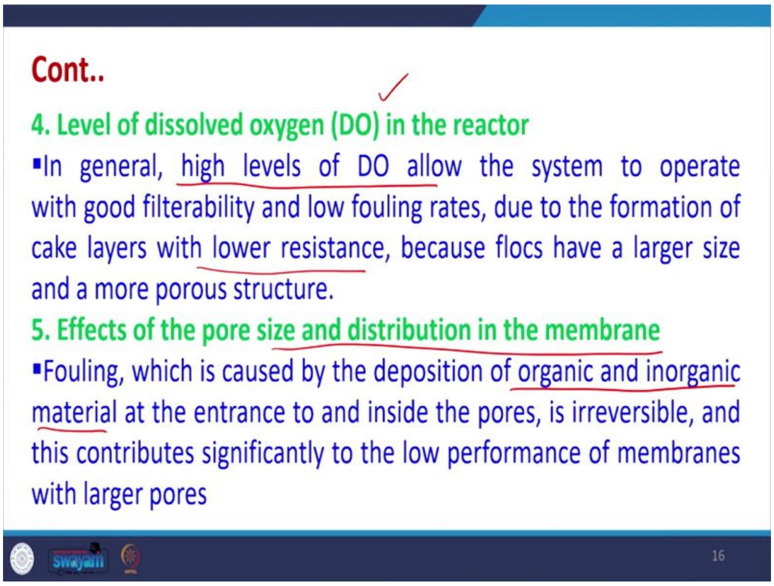


Also the level of dissolved oxygen in the reactor in general, the higher level of DO allow the system the biological system to operate with good filter ability and low fouling rates. So, that means, if we can maintain higher level of DO inside the biological reactor, the fouling in the module will be less due to the formation of cake layers with lower resistance and because flocs have a larger size and they will be blocked easily and the overall structure will be more porous.

So, we have to see that we have to maintain a certain level of dissolved oxygen inside the reactor always now, the effect of pore size and distribution in the membrane. So, what is the pore size of the membrane module this is also important fouling which is caused by the deposition of organic and inorganic materials at the entrance of the pores is irreversible. So, we have to see that the in particular for organic and inorganic material.

So, this can significantly lower the performance of membrane with larger pore. So, we have to select pores which are smaller in size, so, that the organic and inorganic materials are blocked beforehand and they do not go inside the pores because if they go inside the pores, then they will be blocking the pores. So, it is better to have decide the pore size and its distribution beforehand.

So, effective pore size should be known and for the system where organic and inorganic materials are very high after biological treatment, we have to see that the pore size is much smaller as compared to the size of organic and inorganic material, so, that the blockage of the pore does not happens.

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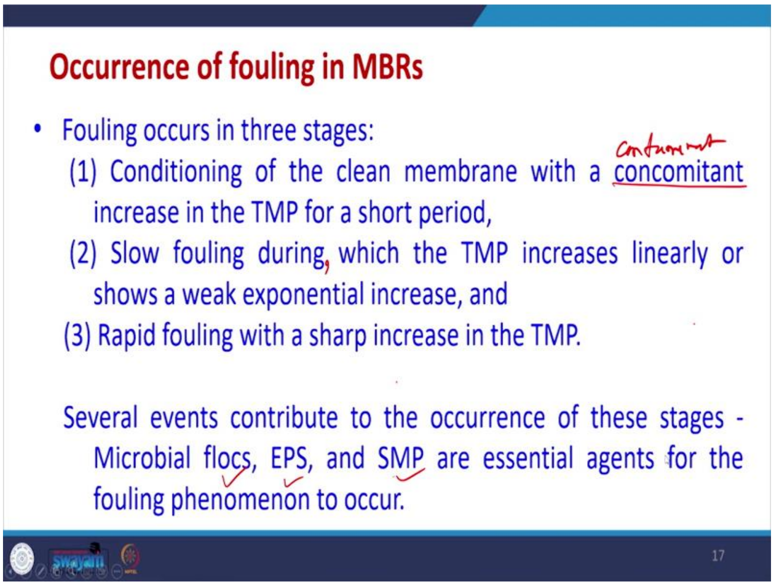


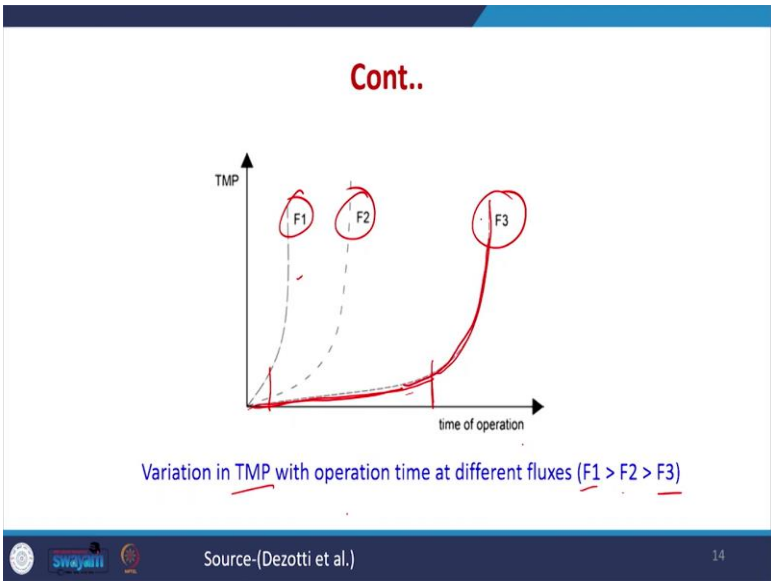


Now, Occurrence of fouling in the MBR. So, fouling occurs in a number of stages in particular like three stages. So, first that conditioning of the clean membrane with a contaminant increases in the TMP. This is contaminant increases in the TMP for short period. So, this is the first stage, then here the conditioning happens during the initial treatment itself.

Now the slow fouling during which the TMP increases linearly are show as a weak exponential increase. So, in the secondary stage, the slow fouling will happen, and the TMP will slowly increase, after that, the rapid filing will happen with sharp increase in TMP. So, this we have seen here also, there are stages where there is nothing is happening only linear increasing happening, and then we have exponential increase in the fouling which is happening. So, this is the stage several events contribute to the occurrence of these stages, like microbial flocs, EPS SMP are essential agents for fouling phenomena to occur.

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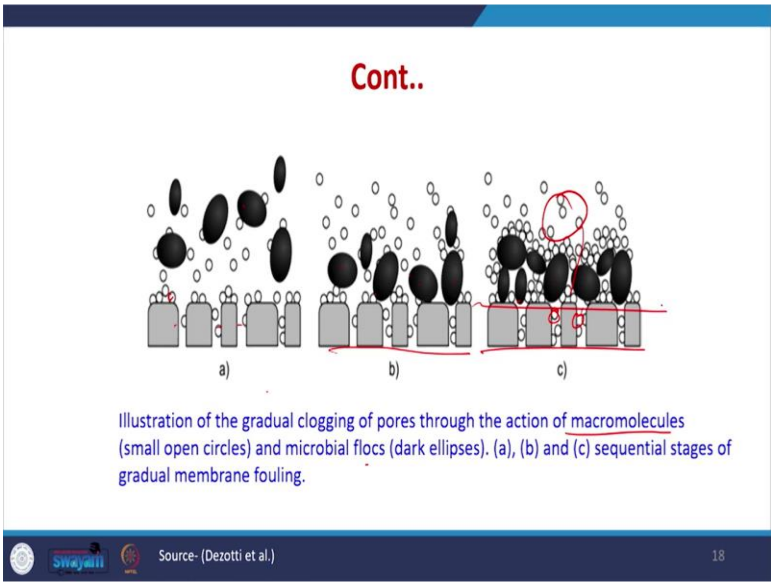


So, we can see the different stages. So, here the gradual clogging of the pores through the action of macromolecules, which is shown by open circle and then the microbial flocs, which are bigger in size the dark circles is shown. So, we can see initially the pores are getting blocked by these macromolecules, after that, we can see, these microbial flocs are also slowly and slowly blocking this fouling this membrane and after a certain time, both are fouling and in fact.

Because these microbial flocs are now a blocking the pores and these microbial flocs are bigger in size as compared to the pores of the membrane. So, overall the smaller size pores that means, the micro molecules are also getting blocked and they are not able to pass though their sizes is smaller. So, overall blocking or fouling is happening here. This is there.

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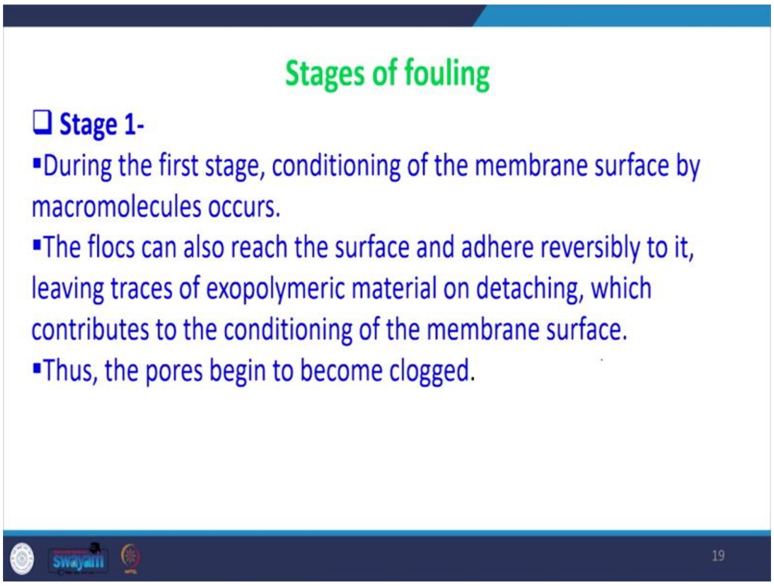


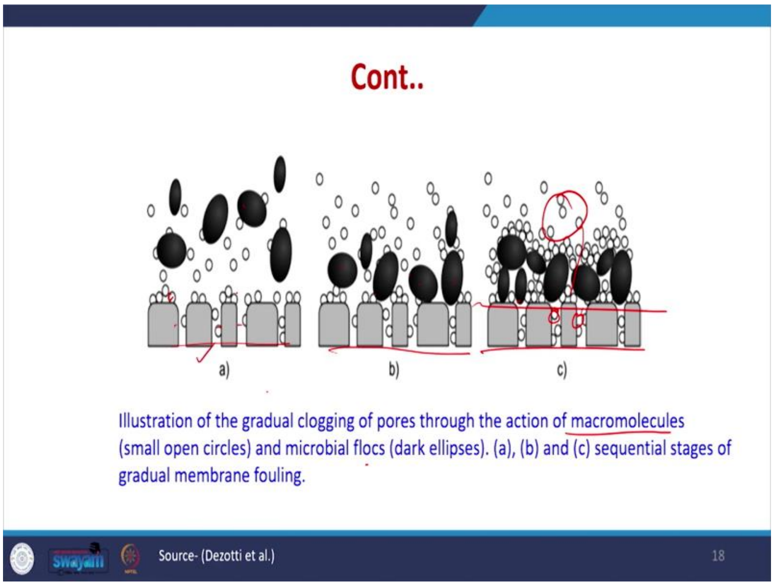


Now, we can see in the stage one during the first stage that conditioning of the membrane surface by macromolecules occur. So, we can see here the conditioning is happening and the floc s can also reach a surface and adhere reversibility to it, leaving traces of exopolymeric material and detaching which contributes to the conditioning of the membrane surface. Thus pores are becoming clogged here.

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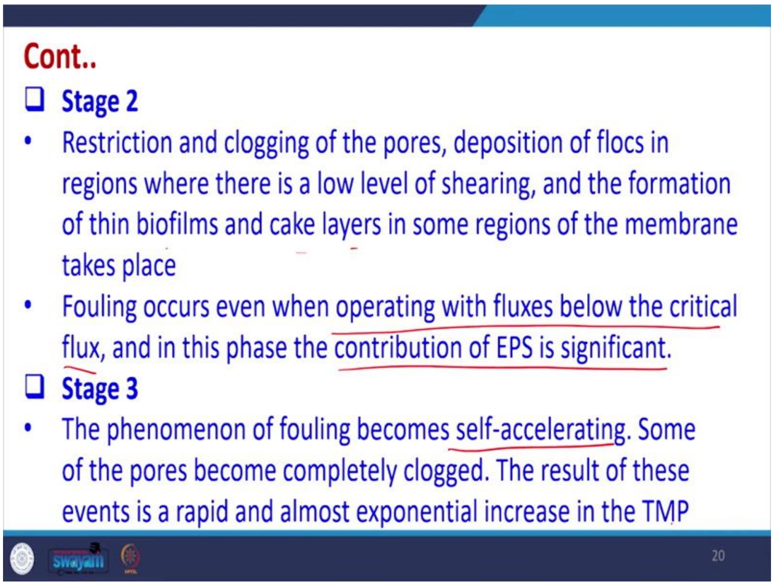


In the secondary stage restriction and clogging of the pores, deposition on the flocs in the regions where there is a low level of shearing and the formation of thin biofilms and cake layers in sub region of the membrane take place. So, that means the microbial floc is coming they are now slowly slowly blocking. Fouling occurs when operating with fluxes below the critical flux. So, under this condition, if you are operating below that critical flux then fouling also happens in this phase the contribution of EPS is significant. So, extra polymeric substances which are coming, they also are blocking.

Then the stage third, the phenomena fouling becomes self-accelerating, some of the pores are totally clogged. And the result of these event is rapid and almost exponential increase in the transmembrane pressure the TMP.

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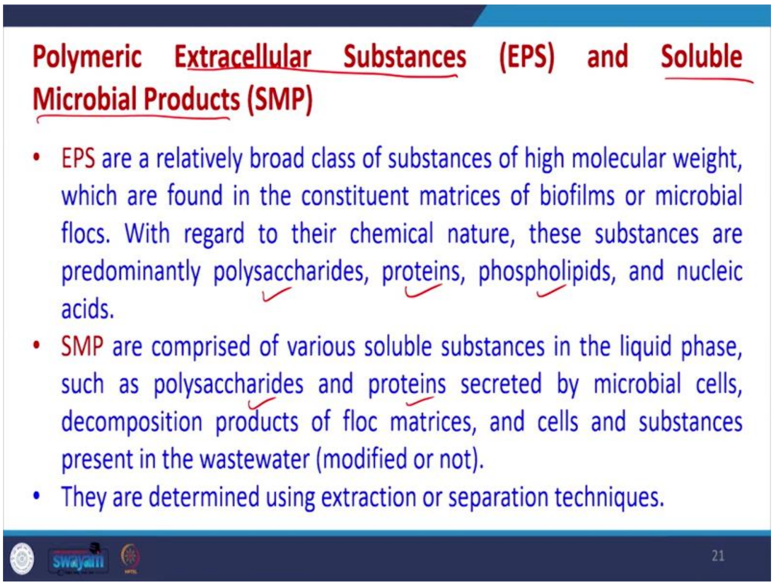


So, we have two types of substances or products which affect one is called polymeric extracellular substances, the EPS, the EPS and the soluble microbial products. So, EPS are relatively broad class of substances of higher molecular weight, which are found in consequent mattresses or biofilms and microbial flocs with regard to their chemical nature. These are predominantly polysaccharides protein phospholipids are nucleic acids.

So, they actually affect the fouling of material a lot. Similarly, SMP the soluble microbial products are comprised of various soluble substances in the liquid phase such as polysaccharides proteins secreted by the microbial cells and decomposition product of the floc matrices and cells and substances present in the wastewater. Both of them are determined using extraction or separation techniques, but they affect the following a lot. How to operate and take care of the fouling in the membrane bioreactor?

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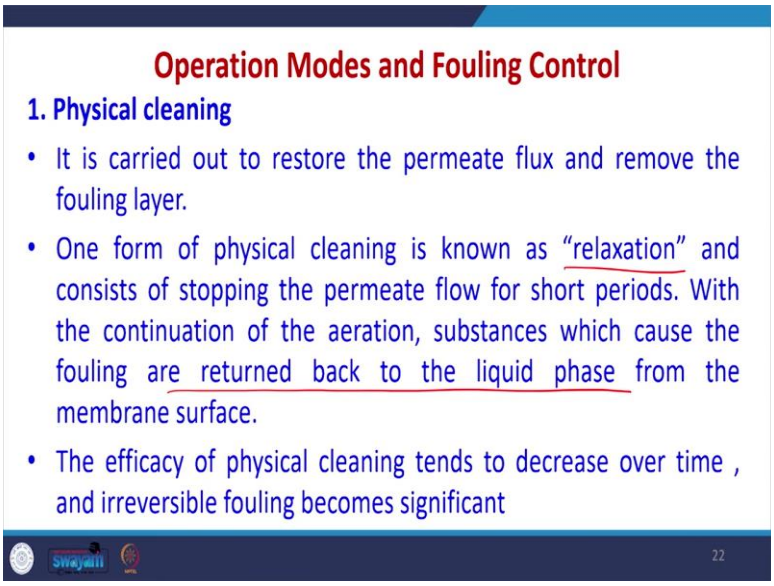


So, one of the option is to carry out the physical cleaning it is carried out to restore the permeate flux and remove the fouling layer. So, this is physical cleaning can be performed after a certain time for the membrane module, one form of the physical cleaning is called as relaxation and consists of stopping them permeate flow for short period with the continuation of the aeration substances which caused the fouling are returned back to the liquid phase from the membrane surface. The efficacy of physical cleaning tends to decrease over time and becomes irreversible. After certain time this is possible.

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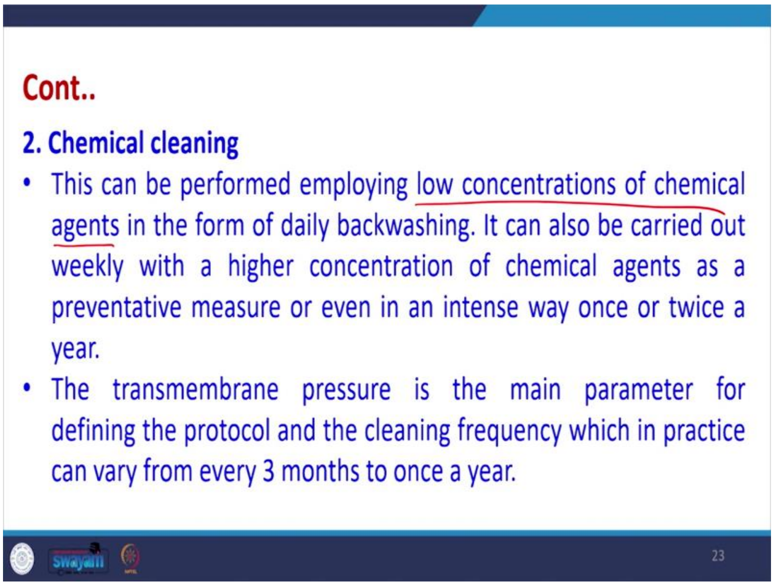


Then we have chemical cleaning, this can be performed by implying low concentration of chemical agents in the form of daily backwashing. So, that means, we have to daily back wash the membrane module and it can also be carried out weekly with a higher concentration of chemical substance. So, if we are carrying out the backwashing daily, we can use the lower concentration of chemical agents if we are carrying out weekly we have to use higher concentration of chemical agents as a preventive measure and this is then.

The transmembrane pressure is the main parameter for defining the protocol and thus the cleaning frequency which is in practice can vary from every three months to once in year. So, depending upon the TMP at which the system is operating, we can decide that chemical cleaning frequency whether it should be daily or weekly or three days after this will depend upon the transmembrane pressure.

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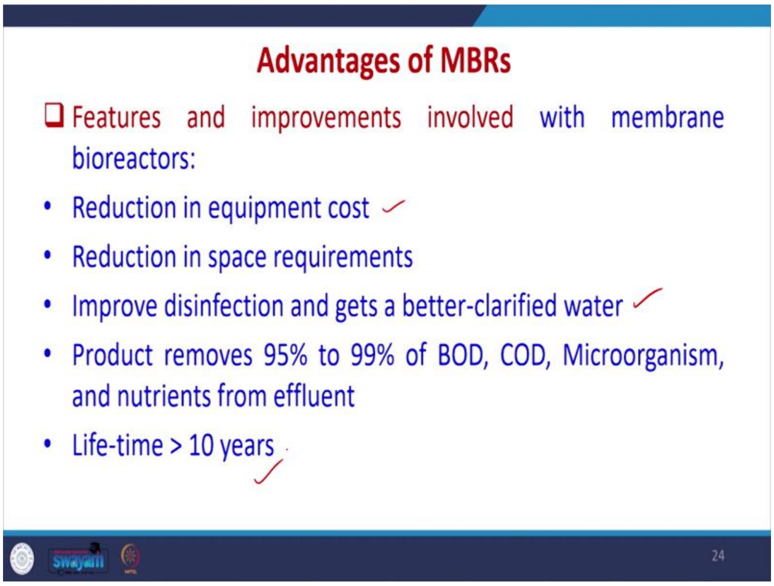


There are certain advantages of MBR. So, there are many features and improvements involved in the membrane bioreactors, one is the reduction in the equipment cost because we are not using the clarification system then also we do not need to use the sand filtration unit etc. So, we can have reduction in the equipment costs. Certainly the space requirement is much lower as compared to the activated sludge system followed by a clarification unit and a sand filtration unit.

In improves the disinfection as compared to that other system and get some better clarified water the product this system removes 95 to 99 percent of the BOD, COD microorganisms and nutrients from the effluent a lifetime is maybe greater than 10 years depending upon how we operate the membrane bioreactors and how we are taking care of the fouling. So, MBBR certainly have few advantages and these systems are growing and their operation is slowly and slowly getting well known to the operators.

So, depending upon the reactor size the type of wastewater to be treated, the membrane bio reactors are now becoming common in the wastewater treatment and they are being integrated with the biological treatment process where the strength of wastewater is higher or the strength of wastewater is lower, but the quantity of wastewater is higher as compared to earlier means.

So, the integration of membrane bioreactor with the traditional system is increasing and with the knowledge which is being gained and also with the quality of the membrane module materials, which is increasing the uses of membrane bioreactor in the wastewater treatment system is also increasing.

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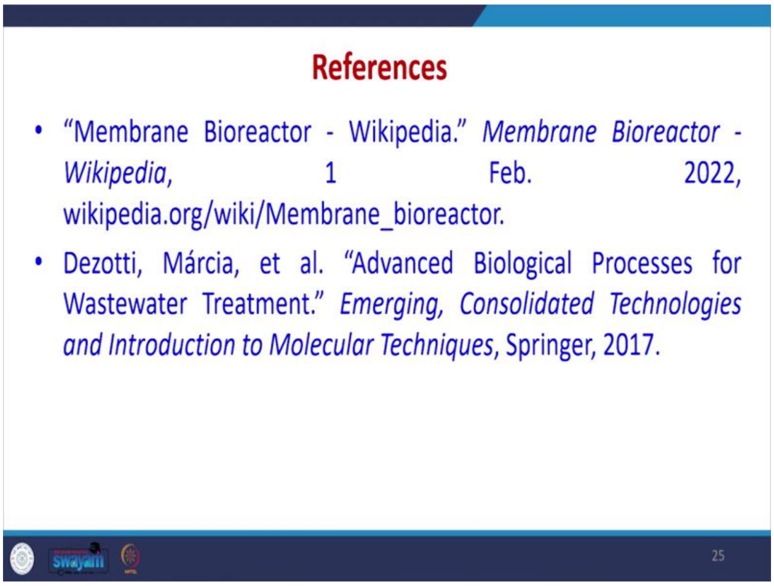


These are the different references which have been used in this lecture. You can use refer to study these references further. And thank you very much. We will continue further with the Advanced Biological Wastewater Treatment in the next lecture. Thank you very much.