Course Name: Industrial Wastewater Treatment

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Lecture-2: Advanced Oxidation Processes

So, welcome back. We are in module 4, lecture 2 and we will be talking about the membrane processes for wastewater treatment. So, we know that the membranes can be used not only for the water treatment, but it can also be used for the wastewater treatment, and we will find out that how the membranes can be applied for the wastewater treatment in this lecture. So, the concepts covered in this lecture includes the introduction to the membrane processes. We will talk about the membrane process terminologies. We will also talk about the membrane process classifications.

So, the membrane process is widely used in various stages of water as well as the wastewater treatment so that we can achieve the desired water quality as well as we can also meet the effluent standards by using the membrane process. So, when we talk of the water, so you must have seen that at your homes you are having a RO system which also houses the membrane. So, there the membrane is used so that we can remove the total dissolved solids which are present in the water which are causing not only hardness, but they may also cause a certain disease because of presence of the certain metals in it. So, there we use the membrane process so that we can clean the water, we can treat the water to the required desired water quality.

In the wastewater treatment however, the membranes are used so that we can contain the sludge, or we can also contain the MLSS or MLVSS which is going out of the reactor. So, it enhances the quality of the effluent to a greater standard. So, when we are having the wastewater treatment processes, so we can have the membrane bioreactors. In membrane bioreactors, we are providing the membrane so that it may contain the sludge that may otherwise go out with the effluent, or we may require a secondary settling tank so that we can settle the sludge before we take the effluent to the disposal point. So here, it not only enhances the efficiency of the reactor, but it also reduces the footprint of the reactor.

So that's why the wastewater treatment also uses the membrane processes so that not only the footprint will reduce, but the cost of the reactor will also reduce substantially in that case. But the cost of membrane may also be a matter of concern. So, the membrane filtration, it involves the separation that is the removal of colloidal as well as the dissolved matter and which is having a particle size range of around 0.0001 to 1 micrometer. So here, the membrane filtration is used to remove the colloidal as well as the dissolved matters which are present in the water or wastewater.

Similarly, the membrane serves as a selective barrier that will allow a certain constituent to pass through it and whereas it will retain certain other constituents depending upon the number of factors, whether it can be size, it can be shape, it can be charges which are present on the constituents which you want to remove from the wastewater or water streams. So, we can see here that membrane is used so that we can filter the unwanted materials. For example, we can see here that the feed is coming to the membrane and this feed may contains a number of constituents and let's say that these constituents which are bigger in size so that you want to remove, so they do not pass through the membrane and we see that the permeate or the treated water it goes out of the membrane so it may contains the constituents which are desirable which we do not want to remove whereas the constituents that we want to remove so they are basically taken away by the water in a highly concentrated solution that is also called the retentate, it is also called the concentrate. So that's how the membrane process occurs and that's how we use the membrane for enhancing the quality of the water or the wastewater. So, there are number of terminologies that we generally used during the membrane processes.

So, first is the feed stream. The feed stream generally refers to the influent which enters the membrane module. So, it is called the feed stream because the influent that is being subjected to the membrane for the treatment so that is basically also known as the influent and that is also called as the feed stream. So, we will refer to the influent as the feed stream in our coming lectures. Similarly, the water that passes through the membrane, which is purified during the filtration process, so this is also known as the permeate.

So, we can see that the water that is passing that is clear that is purified that is passing through the membrane so this will be referred to as permeate. Similarly, the concentrated solution or the suspension that remains after the filtration process that is you have seen in the previous diagram that the water which contains a very high concentration of the species which are removed by the membrane, so it is known as the concentrate, or it is also called as the reject. So, these are the substances that are the rejected by the membrane. Similarly, there is another term that is called the flux. So, the flux is the rate at which the liquid passes through the membrane per unit area.

So, it is the flow per unit area that is passing through the membrane so that is known as the flux. So, if we talk about the units of the flux so this will be represented in liters per square meter per hour and shortly it is called LMH. Similarly in the PSI units it may be termed as gallons per square feet per day, so it is also known as GFD in the short term. So, the membrane process terminology also involves the fouling that is fouling means that is accumulation of particles, accumulation of the microorganism or accumulation of organic substances which are present in the water or wastewater on the surface of the membrane. So, this fouling reduces the performance and efficiency of the membrane because what happens is that these accumulations it will clog the pore size, the pores through which the water is passing so this may reduce the efficiency and the performance and this will also reduce the flux that is passing through the membrane.

So, the fouling is a very very important and we can say it is a matter of concern that the fouling of the membrane will not only reduce the life of the membrane, but it will also increase the cost of the treatment by using the membrane process. So that's why we always see that the fouling may be reduced to a great extent so that the efficiency of the membrane process may go down. Similarly, when we talk of the cleaning of the membrane so we can either clean it where it is so it is called the cleaning in place CIP that is the process of the cleaning of the membrane when they are in position when they are basically being used so we can clean them at their position only. So that is called cleaning in place that is it may be done by passing through air or by backwashing the membrane so that it may be cleaned it may be washed at the place where it is housed. So otherwise we have to take out the membrane from the system we have to disassemble the system and then you have to stop our operation and then we have to clean it by different processes for example we can go for the physical cleaning where we use only water for cleaning the membrane surface or we can also use the chemicals so that we can clean we can basically bring the flux back to its original position so that is basically known as the out of the place cleaning.

Similarly, it is because of the fouling mechanism so it is very very important that we go for the pretreatment of the water or wastewater that is being subjected to the membrane. So here the processes which are applied to the raw water before the membrane filtration so that they can reduce the contaminants that may cause fouling or damage to the membranes so that process is known as the pretreatment process. Similarly, after the membrane filtration happens so after that whatever the processes are applied so that we can enhance the quality further so that is known as the post treatment which is applied to the permeate or the filtrate that we are getting from the membrane filtration so that we can meet the specific water quality standards. Similarly, the selectivity of the membrane is also a very important term this means that the ability of the membrane so that it can discriminate between the different substances for example it based upon the size of the constituents it may be based upon the charge of the constituents which are present in the water or it may be based upon the other properties like shape of the constituents that are present in the water. So based on that the membrane may discriminate the different type of species so that they can be removed from the system and whatever the species we want in the water so that may go into the filtrate or the permeate.

Similarly pore size also plays a very important role in the membrane that which means that the size of the openings of pores which are present in the membrane so that is called the pore size, and this allows the size of the particles that can pass through it when we are talking about the filtration mechanism. Similarly, the rejection means that is the percentage of a particular substance that is prevented from passing the membrane so that is called the rejection. For example let's say we are having a very high TDS in the water so that TDS we do not want to come into the permeate or into the filtrate so whatever the percentage of the TDS that goes along with the concentrate or the retentate so that is called the rejection or the percentage of the TDS that is going into the rejects or that is going into the concentrate so that is called the rejection. So, then we are having a very important term here that is the osmosis. So, the osmosis means that the movement of the solute molecules from an area of lower solute concentration to an area of higher solute concentration when we are separating these two solutions by a semi-permeable membrane.

So, we can see here that this is a reactor in which we are having two types of solutions one is having a fresh water here and other is having a salt solution here. The concentration of the solvent is higher on in the fresh water whereas the concentration of solvent is lower in the salt solution and similarly the solute concentration in the fresh water is low whereas the solute concentration in the saltwater is very high so what happens that the water from the solvent from here it starts moving from the higher concentration to the part which is having a lower concentration so of the solvent until the concentration of the solute in both the part it becomes constant, it becomes same. So that is how the movement takes place, and this process is called osmosis, and this happens when we are separating these two solutions by a semi permeable membrane which will allow a certain type of molecules to pass through it. For example, here the water molecules can pass through the membrane. So, such type of process is called osmosis.

So forward osmosis means that is when we are separating the two solutions by a means of a semi permeable membrane the water moves from the feed solution to the more concentrated draw solution. So, this called the forward osmosis. It is similar to the osmosis process in which the movement of the water is taking place in the direction in which the osmosis happens. Whereas the pressure retarded osmosis means that it harvests the energy that is generated from the osmotic pressure difference. For example, when we talk of the osmosis so there may be a pressure difference because of this movement so that may be generated here.

So, this is basically harnessed, and this is called pressure retarded osmosis. Whereas the reverse osmosis means that is we are having the reverse process happening here. So, this means that when we are allowing the water from the higher concentration of solute towards the water which is having a lower concentration of the solute so in that case we are going against the osmosis, and we are going against the osmotic pressure. So, this means that we have to apply a certain pressure so that we can achieve this movement from the higher concentration of the solute towards the lower concentration of the solute. So, this means that this pressure must be greater than the osmotic pressure which is existing when we are not applying any pressure because the water is moving in the reverse direction, so this process is known as the reverse osmosis.

So, we can see sketch for the membrane process so here we are having the feed water so this feed water may be having a flow rate of Qf here and Cf is the concentration of the feed water concentration so we can have the concentration of any contaminant or the target species that we want to remove so this is basically will be denoted by Cf whereas Pf is the feed water pressure. The pressure at which we are injecting our feed water into the membrane module. Similarly, the water that is coming out from this membrane, so this is called permeate and the flow rate of the permeate is known as the permeate flow rate whereas the concentration of the species that we are targeting so the concentration in the permeate is called permeate concentration and the pressure at which the permeate is coming out, so this is known as the permeate pressure. Similarly the reject that is going out of the membrane that is being rejected by the membrane so this is called the concentrate flow rate so this concentrate flow rate may have a certain concentration of a targeted species like for example when we talk of TDS so it may be having very high concentration of the TDS into it so this is called the concentrate concentration and similarly the pressure at which the concentrate comes out is called the concentrate pressure. And the Kw and Ki you can see here so they are basically the water and solute mass transfer coefficient through the membrane.

So, we can classify the membrane separation process based upon the pore size, based upon the driving force, based upon the application that we are doing, based upon the configuration of the membrane, based upon the specific processes. So based on the pore size we can divide the membrane processes into microfiltration, ultrafiltration, nanofiltration and reverse offices. So as the term suggests the pore size are different for different type of membrane filtration. For example, when we talk of the microfiltration so it is having a pore size of nearly 0.1 to 10 micrometers and such type of membranes can be used for removal of the suspended solids because the size is larger it can also be used for the removal of the bacteria when the size is less than 1 micrometers and similarly it can also be used for the removal of the large colloidal particles.

So, when we talk of the ultrafiltration so in that case, we are having the pore size of nearly 0.01 to 0.1 micrometers and it can be also used for removal of the colloids, it can be used for removal of bacterias, viruses, proteins and macromolecules. In nanofiltration the pore size is nearly 10-3 to 10-2 micrometers, and it is used for the selective removals of certain multivalent ions because of its size and the organic matter that is the dissolved organic matter as well as the color which may be imparted because of the dissolved constituents in the water. And lastly, we will talk about the reverse osmosis where the pore size may be around 10-4 micrometers so this may be used for the removal of the dissolved solids, dissolved ions similarly it may be used for the desalination of the waters, it may be used for the removal of the organic compounds as we are targeting the wastewater and other impurities which are present in the water or wastewater.

So we can see here that the raw water basically it may go through the different type of filters for example when we talk of the microfiltration so it is having a pore size of 10-2.1 microns and it can remove a number of impurities which are there right for example suspended particles are there, we are having the oil emulsifiers, bacterial cells, colloidal particles so they all basically can be removed from the microfilters whereas the other things for example the viruses, the macromolecules, the proteins so they may leach so they may go into the filtrate right. So, then we have to use ultra filtration where the size may be around 0.1-0.001 microns, and it may remove further the materials, and it may lead only to the leakage of the monovalent ions or divalent ions or some molecular organic groups so they may go into the filtrate.

For further filtration we may apply the nanofiltration where nanofiltration is having a size of nearly 0.01-0.001 microns and it may lead to the release of the monovalent ions here and when we go for the reverse osmosis process which is having around 10-2.2-4 microns of the pore size so this may lead to the demineralization, it may lead to the removal of the ions which are present in the water and we can get a desalinated water in that case. And as we see that as the type of the filters are changing so we can also see that the pressure that we have to apply is also increasing.

So basically, when we talk of the microfiltration it is 0.2-5 bars, when we talk of the ultra-filtration it is around 1-10 bars, when we talk of the nanofiltration it is 5-10 bars, whereas for the reverse osmosis process a very high pressure may be needed it may be around 10-150 bars. Similarly, the driving force can also classify the membrane processes where we can have the pressure driven processes where we talk about the RO, nanofiltration, ultra filtration so we have to apply a very high pressure so that we can overcome the osmotic pressure, and the water can be forced through the membranes as the pore size is very very small. Similarly, we have the concentration driven process for example when we have talked about the powered osmosis so in that case the osmotic pressure difference between the feed and the draw solutions so that basically provides the driving force. Similarly, we can also have the electrical driven processes which are called electrodialysis so here the ions basically they move under the electrical field, which is applied, and we are having a certain ion selective exchange membranes so they can allow certain types of ions to go through them and that's how we can separate out the different type of ions and we can get the water of the desired quality.

So based on the application we can have the water or waste water treatment that we are talking about so we can use micro filtration here we can use ultra filtration, nanofiltration, the RO or the membrane bioreactor so here it can be used for the municipal water treatment, it can be used for the industrial waste water treatment, it can be used for the municipal waste water treatment also, it can also be used for the desalination purposes. So here as we have already talked about the membrane bioreactor so the membrane bioreactor can be used for the treatment of the wastewater so or we can talk about the anaerobic membrane bioreactor so it can enhance the sludge retention time to a very great extent. So as we know that the hydraulic retention time and sludge retention time or the sludge age so they are different in the bioreactors so this means that when we are applying a membrane process to it, it may hold the sludge for a longer time so that the sludge age or the sludge retention time it increases many folds and it has been found that the sludge retention time may go up to more than 100 days in such type of reactors. The membrane process can also be used for biomedical applications where ultra filtration and membrane filtration may be used for the blood filtration, for protein separation as well as for the pharmaceutical processing. Similarly, the membrane processes can be used for the food and beverage industries where the ultra-filtration and nanofiltration can be used for the clarification, for the concentration, for fractionation of various liquids so there the ultra-filtration and nanofiltration can be applied.

Similarly, for chemical and petrochemical industries the separation and concentration of chemicals, purification of process water we can use RO as well as the nanofiltration techniques. For the gas separation also, we can use for example when we want to separate out the gases like hydrogen, carbon dioxide, methane we want to produce gases of very high quality or purity so in that case we can also use the gas permeation process. So based on the configuration we can divide the membrane process into the spiral wound modules we can divide it into tubular modules we can have the plate and frame modules. So, the spiral wound modules mean that is we are having the flat sheets so they are bounded around the permeate tube in a spiral manner so that is basically called the spiral wound modules. So, the application may be in the reverse osmosis process or nanofiltration or the ultra-filtration.

Similarly, when we talk of the tubular module so we can have two types of arrangement here that is one is called the hollow fiber and other is also known as the tubular membrane. So, these types of membranes so they may be employed for the processes like micro filtration and the ultra filtration. Similarly, we can have plate and frame modules where the membranes are placed between the plates and the frames and they may be used for laboratory scale filtration, industrial processes they may also be used for the wastewater treatment also. So based on the specific processes for example when we have just now talked about the membrane bioreactors so this biological treatment with membrane filtration will reduce the cost of the secondary settling tank and it may also enhance the efficiency of the membrane bioreactors in the sense that it will enhance the sludge retention time of the anaerobic membrane bioreactors to a great extent it will reduce the footprint it will also reduce the cost of the treatment processes. So, it may be used for municipal as well as the industrial wastewater treatments.

Similarly, we can have the electrodialysis process where the ion exchange membranes can be used, and these types of processes may be used for the desalination for the treatment of water which is laden with very very high concentration of salts and similarly it can also be used for the electrodialysis reversals. Similarly, we can also used pervaporation where the vaporization of a liquid through the membrane for the separation of azeotropic mixtures or the dehydration of organic solvents can be utilized. So, the removal mechanism in the membrane filtration it relies on the selective permeability of the membrane so that they can separate the particles and solutes from the solvent based on the size, shape, charge as well as the other properties. So here we can see that the mechanism for micro filtration ultra filtration nano filtration or reverse processes that we have just now discussed so it basically may differ for different type of filtration processes. For example, when we talk of the micro filtration, so the size is nearly 0.1 to 10 micrometers so here we see that the mechanical filtration is the process that is basically used for the removal mechanism. So, the larger particles for example the suspended particles, the bacteria or the larger polluted particles so they are physically blocked by the membrane. So, the particles which are less than the pore size of the micro filter so that can pass through the membrane. So mechanical filtration takes place here and similarly the sieving effects also basically takes place here that is the smaller size particles they pass through the membrane whereas the larger particle size, so they are retained on the membrane surface. So, for the ultra-filtration also we are having the size of around 0.001 to 0.1 micrometers. So here the ultra filtration basically works on the mechanism of size exclusion so where it allows the smaller particles like colloids, bacteria and viruses, proteins and macromolecules so they are allowed to pass whereas the larger particles they basically are hindered by the surface of this thing. And similarly, the larger particles they are hindered by the molecular structure of the membrane also that is called the steric hindrance. So, we are having the nano filtration where we see that the pore size may be around 0.001 to 0.01 micrometers and here also the size exclusion plays a very important role.

It may be used for the removal of multivalent ions similarly organic matters and colors basically can be removed and it can also be based upon the charge-based rejection methods that is the membrane may have a charge that repels the ions of the similar charge. So, we can have two types of mechanism here the size exclusion as well as the charge-based rejection. Then reverse osmosis where we are having a very very small size of the pores, so they also prevent the passage of the ions, molecules and particles which are larger than the size of the membrane pores. And similarly, so the size exclusion also plays a very important role similarly the drag molecules that is water molecules are forced through the membrane by the applied pressure it leaves behind the dissolved ions and other impurities behind. So, the solvent drags also plays a very very important role in the removal mechanism by RO process.

So, we can see here that the first part here is the removal by the size exclusion so you can see here that the bigger particles they remain on the top of the membrane whereas the smaller size particles, so they are passing through the membrane. So, this is called as the size exclusion process. Similarly, the second part may be the adsorption that is some type of molecules or some type of constituents in the water so they may be hydrophobic in nature so they may remain adsorbed onto the surface of the membrane and whereas the particles which are hydrophilic in nature so they may pass through the membrane. So, this is known as the adsorption process. Similarly we can have we can see that there can be certain charges on the membrane for example you can see here that the membrane is having the positive charge here whereas the particles which are having the positive charge so they may be repelled and they may not pass through the membrane whereas the particles which are neutral or particles which are negative so they may be allowed to pass through the membrane so this is called a electrostatic repulsion mechanism.

Similarly we can also have the adsorption on the fouling layer when we are using the membrane for wastewater treatment processes so in that case a layer of the fouling basically may be deposited on the surface of the membrane and this may lead to the adsorption of the molecules which are similar in nature and we see that such adsorption may not allow the certain particles which are basically linked to the surface of the fouling layer and whereas the rest of the molecules they may be allowed to pass. So, we stop here in this lecture, and we will be talking about the various type of membranes that we use and how basically we can design the membrane system in our coming lecture.

Thank you.