Course Name: Industrial Wastewater Treatment

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Lecture-3: Advanced Oxidation Processes

Welcome back, we are in module 4, lecture 3 and we are discussing about the membrane processes for wastewater treatment, and we will continue our discussion on this topic in this lecture also. So, the concepts covered in this lecture will be on membrane configuration, the membrane operations, similarly the microfiltration and ultrafiltration processes, the typical operational flow mode of the membranes in these processes, mass balance analysis of the crossflow mode of the membrane, about the reverse osmosis systems and the typical flow diagram for the reverse osmosis membrane process with pre and post treatment systems. So, we are talking about the membrane configuration. So, when we talk about the membrane in the field, so the term module is applied to describe the complete unit of the membrane. So, when we talk of the membrane module, so this means that it may contain the membranes inside it, and this may be protected by the pressure support structures which is also having the feed inlet and feed outlet for the various permeate as well as retentate that is coming out of the module. So, this is module is the overall support structure and we can see here that the module may contain a certain housing structure which supports the membranes which are there inside the module and applying the pressurized feed.

So, this may go into the membrane system and the retentate may pass or the rejected or the concentrate may pass from the one side whereas the permeate or the clear water may pass from the other side. So, this whole system where a number of membranes may be housed, and this is known as the module. So, the module is used for the water treatment processes. So, this may be containing the membranes like tubular membranes, it may be containing the hollowfiber membranes or it may be containing the spiral wound membranes.

So, the plate and frame as well as the pleated cartridge filters, so they are also available, and they may also be housed in a certain module. So, when we talk of the tubular module, so the membrane is cast on the inside of the support tube. So, we can see here that the tubular membrane may be there which is having a shape of the tube and these tubular structures, so they are housed inside the entire module. So, you can see a number of these tubes which are housed in the support's tubes, and this is known as the single module. And what happens that the feed water is pumped through the feed tube, so we are pumping the water through this feed tube, the permeate that is there, it is basically coming out of the feed tube and the retentate or the concentrate is passing outside the tube.

So, the concentrate it flows through the feed tube, and it goes out of the system. So, we can collect the water, the permeate from one port and we can collect the reject from the other port, whereas the feed may be applied from another port. So, that is how the modules basically may be arranged. So, these units can be used for the water with high suspended solids which is having a higher plugging potential. So, such type of tubular modules can be used for treatment of water which contains very high amount of suspended solids.

So, the tubular units are having an advantage that it is very easy to clean, and we can use the chemicals, we can circulate the chemicals through these tubes and or they can also be cleaned by pumping a foam ball or sponge ball through the tubes, so that it can mechanically wipe the membranes. So, the tubular units produce at a low product rate, so the amount of the permeate that is being produced to the amount of the volume of the water that is applied, so the amount of permeate is lower and these membranes are generally expensive in nature. So, then we can have another type of membranes which are known as the hollow fibers. So, these hollow membranes, so they are housed a number of hollow membranes, thousands of hollow fibers, so they are housed in a single module and feed water may be passed through these tubes and the concentrate may go on to the other side whereas the water may flow from inside the tube and water may flow outside the tube and this may form the permeate. So, that is how you can see that the hollow fiber module is arranged, and these hollow fiber modules can have the feed which is applied inside of the fiber that is it goes through the fiber and the flow is called inside outflow or the flow may be applied, the feed may be applied outside of the fiber and the permeate may go inside the fiber.

So, it feed may be applied outside to the fiber also, the feed may be applied inside the fiber also, so it is called inside outflow or outside inflow. So, then we can have a spiral wound membranes where the, we can see the flat sheet membranes, so they are spaced by a permeate spacer, then they are basically arranged in a spiral manner or to the perforated pipe. So, this membrane is then sealed from the three sides and such type of membranes you can see that these are the membranes which is there, so these membranes are spaced through which the water basically passes and the water is filtered and through the spacers the water comes out and we can see that the tube which is the permeate outlet, so it is the thin film composites, so they are wound in a spiral manner on to this tube and with a number of spacers which are placed in between each flat sheets. So, these flat sheets are also called the thin film composites, and they are generally used in the spiral wound membrane modules. So, we see here that the feed that is applied to the module, so this basically may pass in a spiral manner in the sense that the water goes from these membranes, it may go into the spacers and slowly and slowly it may go in a spiral manner and will ultimately go to the permeate collection tube on which our spirally wound membranes are being tightened.

So, this may lead to the permeate coming out through the permeate collection tube. So, we can see here that the feed water may be passed and here we are having three modules which are connected in series, so you can see that the permeate collection tube are joined together, so the effluent of one module is becoming the influent of other modules. So, in a series manner it is being passed and we can see that the permeate it comes out from the central tube from the spirally wound module and the concentrate, which is going out of the system, so this basically comes as a concentrate outlet. So, that is how the spiral wound module is arranged. Similarly, we can have plate and frame structures where plate and frame membrane means that we are having a series of flat membrane sheets and they are wound on the support plates and the water which is to be treated it passes between the membranes of the two adjacent membrane assemblies and the plate supports the membrane here and it provides a channel also so that the permeate may flow out of the unit.

So, these are generally used in the electrodialysis modules. So, you can see here that these sheets which you see here, so these are the flat plate and the frame or we can say the flat sheets, the water passes through these flat membrane sheets and it goes into the space between these two membranes by the support plates and through this the water basically may go out and we can see that the permeate is collected here as well as the water which is not being purified, so it is being going as a concentrate through this module. So, we can also have the pleated cartridge filters which can be applied for the microfiltration of applications, and these are generally used as the disposable units. So, they are mainly used to concentrate virus from the treated water or the wastewater so that we can analyze the virus in the water or wastewater. So, we can also have the pressure vessels, the pressure vessels are to support the membranes.

So, they also keep the feed water, and the product water isolated and the plumbing components which are there, so they are generally used for housing a number of membranes inside them so that they can also bear the pressure that is coming from the feed water. So, when you talk about the membrane operations, so we require a pump, right, so that we can pressurize the feed solution so that it can circulate through the module. Similarly, the pressure is also needed so that the water may pass through the membrane that we are having, and it may pass through the pores of the membrane in the membrane operations. Similarly, a valve is also used so that we can maintain the retentate or the concentrate which is going out of the system and the permeate is generally drawn which is typically at the atmospheric pressure only and we can see that the feed water, it accumulates on the membrane. So, what happens that the species which are being removed by the membrane, so they start accumulating on the surface of the membrane.

So, this leads to the buildup of pressure on the feed side and the flux slowly and slowly starts decreasing as the clogging is taking place, as the reduction in the pore size of the membrane is taking place, so the flux also starts to decline, and this may lead to the percentage rejection also starts decreasing in that case. So, the performance decreases up to a certain level and when the performance goes beyond a certain level or when we see that now the flux that is going out of the membrane has declined to a very low values, for example, let us say it is going below 20 LMH or so, so then we take out the membrane from the systems and then we backwash it, we chemically clean it and again put it back into the system after being cleaned so that their flux levels is enhanced, they are the pore size which have been blocked, so that can be regained, so then we can put it back to the service. So, we can have the three configurations can be used when we are using the microfiltration or the ultra-filtration, so for the first configuration is called the cross flow, so when we are having a membrane here, so when we are passing the membrane tangential to the membrane surface, so this is the feed water that is being applied to the membrane, so the cross filtration means that is the water is passing at 90 degrees through the membrane.

So, this is the permeate that is going out of the system and the rejects or basically the retentate or the concentrate it passes in the same direction as it is not being filtered through the membrane, so this becomes the reject or the retentate, so here this type of system is called the cross flow system, so whatever the retentate or the reject or the concentrate, so this may be recirculated to the additional feed water, so this may be the first type of configuration that can be there and similarly we can also have a second type of configuration where the cross flow is happening in the system, but the concentrate it may be taken to a reservoir from where again it is pumped to the membrane. Similarly, we can have third type of configuration which is also called as direct feed and there is no cross flow that is taking place, so whatever the water we are applying to the membrane, so this is passing through the membrane, so this system is called the direct feed system and the feed water, raw feed water which we are using, so it may be used periodically, so that we can flush the accumulated material on the membrane surface, so it can be used in place cleaning of the membrane.

So, we can see that these three types of the flow modes of the membrane, so that we have discussed just now, so this can be seen here, so we are having a feed pump, the raw water basically is being applied by the feed pump which passes through a screen or a filter, so that we can have the pre-treatment. Similarly, we can use another pump, so that it can be applied to the membrane here and we see that the permeate is passing through the membrane and air or the liquid backwash may be used for cleaning of the membrane in place and similarly the water which is coming out as reject or the concentrate, so that may be taken back to the recirculation pump, so it becomes the part of the feed. So, this is the first type of configuration that we have discussed. Similarly, we can have another type of configuration where the raw water is passed to the screen or the filters and then it is taken to a tank, so this tank basically is having a feed pump which is applying the water to the filters and here also the recirculation is taken back to the tank. So, there is a reservoir there provided so with the crossflow mode, so this is the second type of configuration that we have talked about.

Similarly, we can have the third type of configuration where the direct feed operation is taking place and here the influent pump is there which passes through the screen or the filter and we are having a feed pump here also which again applies it to the membrane and the permeate goes out of the system and here there is no recirculation that is taking place because it is a direct feed operation. So, when we talk of the mass balance analysis of the crossflow mode of the membrane, so we can also now coin a term which is called the transmembrane pressure. So, this is also called the TMT. So, transmembrane pressure means the pressure at which the feed is being applied to the membrane. So, this transmembrane pressure where we call it as transmembrane pressure gradient.

So, this may be calculated by the pressure at which the feed is being applied plus the pressure at which the concentrate is coming out divided by the two. So, the average pressure of the feed and the concentrate minus the pressure at which the permeate is coming out. So, this gives us the transmembrane pressure gradient in kilopascals. If we talk about for the filter module the overall drop can be represented by P is equal to Pf minus Pp where Pf is the feed pressure and Pp is the pressure of the permeate and in the direct feed mode, the transmembrane pressure is given by Pf minus Pp. So, when we talk of the total permeate flow, the flow passing through the membrane, so this may be given by the Fw into A.

So, this Qb is the permeate stream flow rate. So, this is expressed in kgs per second and Fw is the transmembrane water flux rate. So, the rate at which the water is passing, the solvent is passing through the membrane. So, it is in kgs per square meter per second and similarly the A is the area of the membrane through which the flux is happening. The transmembrane water flux is a function of the quality of the feed stream.

It will also depend upon the degree of the pretreatment that the water has received. The degree of pretreatment is higher than we are having a higher flux. If the degree of pretreatment is low, then it may lead to the lower flux to the membrane. Similarly, the characteristic of the membrane also decides about the transmembrane water flux that is depending upon the pore size the flux may be higher, or flux may be lower. Similarly, the system operating characteristics, so that also basically affect the transmembrane water flux through the membrane.

So, the recovery rate may be defined as the flow of the permeate to the flow of the feed water. So, this means that how much recovery of the water or the solvent that we are doing, so that basically is known as the recovery rate. So, it will be equal to the flow rate of the permeate divided by the flow rate of the feed water. Similarly, the rate of rejection that we are talking about here, for example, let us say we are talking about the dissolved solids present in the water. So, the concentration of the dissolved solids in the feed water minus the concentration of dissolved solids in the permeate divided by the concentration of the TDS in the feed water.

So, that will give us the percentage rate of rejection that is how much percentage of the TDS is being rejected by the membrane or how much percentage of a particular constituent is being rejected by the membrane. So, that is called the rate of rejection. So, if we apply the mass balance equation to membrane process, so this will be defined as the flow that is going inside the module or the membrane. So, this will be represented by QF that is the flow of the feed will be equal to the flow of the permeate and the flow of the concentrate that is going out of the system. Similarly, when we talk about a particular constituent that is present in the water that we want to remove, for example, let us say we want to remove the TDS.

So, the concentration of the TDS in the feed water into the flow of the feed water, so that will give us the total mass of the TDS present in the feed water. So, this is equal to the mass of the TDS present in the permeate plus the mass of the TDS present in the concentrate. So, these two mass balances can be used for designing the membrane system. There can be three types of operating modes with respect to the transmembrane pressure. For example, we can have we can maintain a constant flux and we can vary the transmembrane pressure.

So, we know that as the membrane operation increases, so the flux basically goes on declining. So, if you want to increase flux at a constant rate or if you want to maintain the flux at a constant value, so then we have to increase the transmembrane pressure, so that a constant amount of flux can be generated from the membrane. Similarly, if we want to maintain the transmembrane pressure to be constant, so in that case what will happen that the flux will go on slowly and slowly declining because of the clogging and the fouling of the membrane that is taking place and because of which the pore size reduction may take place or there can be a certain deposition of a certain layer on the surface of the membrane. So, these things may reduce the flux if we are keeping the transmembrane pressure to be constant. Similarly, the flux may vary as well as the transmembrane pressure may also vary.

So, this can be the third scenario that can be there when we are using the membrane processes. So, we have already talked about the reverse osmosis process that when we are having the two solutions, one is having a higher solute concentration, other is having the lower solute concentration. So, the solution, which is having a lower solute concentration, the solvent will start flowing from that solution to the solution which is having a higher solute concentration in that case. So, this will happen when we are having separation by a semipermeable membrane. So, this is called the osmosis process.

This osmosis process may depend upon the solute characteristics, it may depend upon the concentration of the solute present in the both the solutions and similarly it will also depend upon the temperature. But when we are reversing this process by applying the pressures which are greater than the osmotic pressure, so such type of system is called the reverse osmosis process. So, we can see here that we are having fresh water being separated by the saline water. Because of the concentration gradient, the fresh water from here will move into the saline water and there will be a pressure difference that will happen here, and this delta p will be less than the delta p naught which is obtained at the equilibrium process. So, the equilibrium process happens when the rate of the flow in both the sides that is from the saline water from the fresh water, so they are same.

So, at that point whatever the pressure difference is created, so this is called the osmotic pressure, or this pressure happens at the equilibrium. If we want to move the saline water towards the fresh water, then we have to apply a pressure, and this applied pressure delta p a should be greater than the delta p naught that is the osmotic pressure. So, that is why we require a very high pressure so that we can achieve the desalination or the demineralization of the water by using a RO process.

So, when we talk of the design of the RO process, so the thing that we will be requiring will be the surface area of the membrane that we require so that we can calculate that how much amount of the membrane can be used or how many modules of the membranes can be used for designing of the RO process so that we can treat the water to up to a certain desired standards. Similarly, how many number of arrays will be required so that also we need to calculate.

So, there are two basic equations that we will be using for the design of the RO processes. One is the solvent flux that is passing through the membrane and other is the solute flux that is passing through the membrane. So, when we talk of the solvent flux that is here in this case the water, so the water flux that is passing through the membrane, so this is a function of the pressure gradient that we have already discussed the flux that of the water that is passing through the membrane in kg per square meter per second. So, this is equal to the water mass transfer coefficient into the average imposed pressure gradient minus the osmotic pressure gradient that is there and when we talk of the average imposed pressure gradient, so this is equal to the pressure of the feed plus pressure of the concentrate divided by 2 minus the pressure of the permeate. Similarly, the osmotic pressure gradient will also be defined as the pressure the osmotic pressure in the feed osmotic pressure of the concentrate divided by 2 and the osmotic pressure of the permeate.

So, this is the flux that is happening through the membrane and this flux can also be defined as the flow of the permeate that is passing through the membrane divided by the area of the membrane. So, this equation gives us the opportunity to calculate the area of the membrane that is required for a given amount of flux that is passing through the membrane. Similarly, we have to also apply an equation which involves the movement of the solute. So, we can have the flux of the solute that is Fi, so this is equal to the solute mass transfer coefficient that is Ki into the solute concentration gradient. So, this solute concentration gradient is again the combination will involve the concentration of the in the feed of the solute the concentration of solute in the concentrate divided by 2 minus the concentration of solute in the permeate.

Now, this will be equal to the flow of the permeate into the concentration of the solute in the permeate divided by the area. So, these two equations will be used so that we can design our reverse osmosis system. If we are seeing a RO process, so this RO process is having a RO unit which is having a high-pressure pump which is required so that the water can be pressurized and water can pass through the membranes so that the reverse osmosis process can take place. So here we need to supply for example, let's say we are having a seawater supply. So, the seawater is taken to a pre-treatment tank where the suspended solids and other high amount of TDS may be removed by certain processes so that we can apply the water which is already treated so that it may enhance the life of the membrane as well as it may also reduce the cost because the membranes are fouled very often so then the cost of the treatment will increase many fold.

So, after pre-treatment the water is pressurized, and it passes through the membrane and the decelerated water basically comes here and this may go to a certain post-treatment process if suppose there are certain other constituents are present in the treated water so this may be treated here and then it may be taken as a potable water. Similarly, the reject that is coming out so this is basically taken to the brine rejection, and this may again be taken back as the feed water after the pre-treatment. So, we stop our discussion here and we will be continuing our discussion on the membrane processes in our coming lectures. Thank you. So, these are the references that I have used in this lecture.

Thank you very much.