Course Name: Industrial Wastewater Treatment

Prof. Alok Sinha

Department of Civil Engineering, IIT(ISM), Dhanbad

Week – 04

Lecture 5: Membrane processes for wastewater treatment

Welcome back. So, we are in module 4 and lecture 5 and we will be discussing about the membrane processes for wastewater treatment. So, the topics covered during this lecture will be on MBR for industrial wastewater treatment that is we will be discussing about how the membrane bioreactors can be used for treating the industrial wastewater. Then we will discuss about the advantages and disadvantages of the membrane technologies. We will also talk about the disposal of the concentrated waste stream that is generated from the membrane processes. We will also talk about the technological advances that needs to be done so that we can overcome the difficulties that we face during the membrane processes.

And lastly, we will discuss about some of the design problems related to the membrane processes. So, when we talk of the treatment of industrial wastewater by MBR, we already discussed that a conventional activated such plant can become a single step process and it can produce a very high-quality effluent which can be potentially reuse as agricultural purposes or for any other reuse like for the industrial purposes also. So, the use of MBR technology for industrial wastewater treatment has gained attention because of the robustness of the process. The robustness of the process comes from the long SRT that can be maintained in the membrane bioreactors because we know that the membrane it retains the biomass and it does not allow the biomass to go outside the reactor which leads to the long sludge retention time or we can say the sludge age increases and because of which there can be development of certain spatial microorganism which may lead to the better removal of the refractory organic matter which otherwise may not take place in the conventional treatment systems.

And the robustness of the system may also lead to bear the load variations as well as the toxic shocks that can arise because of the industrial wastewater that is generated from different type of industries where we can have generation of a toxic effluents. So, the treatment of the industrial wastewater by MBR. So, here we can see that the MBRs are very very efficient in removal of the COD even at a BOD by COD ratio of around 0.1 to 0.2 and we can achieve nearly 80 percent of the COD removal by using membrane bioreactors.

Whereas in the conventional technologies at a ratio of around 0.2 to 0.3 also we can only attain COD removal efficiency of nearly 60 percent only whereas if we talk about the conventional technologies. So, they generally perform at a BOD by COD ratio greater than 0.4 and they may attain a higher treatment efficiency, but it has a limitation that the BOD by COD ratio must be greater than 0.5 or 0.4 in this case. So, that is why it is a very very important technology. So, that can be used at a very low BOD by COD ratio, and it can lead to the removal of COD of nearly 80 percent. So, as we can see that the conventional activated sludge process system we have already discussed about this process, and it is having a biological tank and a settling tank.

So, the settling tank can be replaced by a membrane that can be put as a side stream process. So, this is the first-generation process that has happened that is the membrane was put outside the tank it was doing the work of a secondary settling tank and the retentate or the concentrate that is generated that can be recirculated back to the aeration tank. So, the second-generation technology where the membrane can be submerged into the aeration tank and effluent can be drawn from the membrane and this is known as the submerged MBR. So, this is how the evolution of the membrane used in conjunction with the bioreactor has taken place and we can see that such type of MBR can be very beneficial, and they can also lead to the removal of certain processes which may be required during the conventional treatment process. So, they can actually reduce the cost of the installations.

So, for example, if we see the textile-based water here. So, it is passing through the stream or grid when then passes through the primary settling, then it goes to the oxidation and nitrification, then it goes to a secondary clarifier that is secondary settling, then clarification is needed after which the ozonation of the textile based water needs to be done after which it passes through a sand filter, it passes through the granular activated carbon and we add sodium hypochlorite here. So, that disinfection can be done and later on this water can be directly put into the river or it can be mixed with the fresh water. So, that it can be reused for the industrial purposes. Whereas, if we replace it by the membrane technology or if we install a membrane bioreactor in place of this.

So, we can have a lot of units that can be curtailed for example, we may not require the primary settling or we may require a here micro strainer here after which it can go to the oxidation tank or the aeration tank and then it can go through a side stream membrane and the side stream membrane the permeate basically may go for the ozonation purpose and the retentate or the concentrate may be again taken back to the aeration tank. Whereas this after ozonation the water may go to the equalization chamber and after the equalization chamber we can also add here sodium hypochlorite for the disinfection purpose at this point only and then it can go to a tank where the dilution may be done by the fresh water and then the water can be used back by the industry. So, in this way we can see that a number of units like for example, here the secondary settling tank, the clary flocculation. So, these all systems have been removed when we are using MBR in place of the conventional treatment systems. Similarly, we can see that the sand filter, the granular activated carbon or these all processes are removed during the treatment by using the membrane bioreactor.

So, this leads to not only the compact treatment scheme, but it also leads to the reduction in cost in some way and that is we do not need to have a bigger installation like secondary settling tank or clary flocculator. So, these things may be removed similarly we have removed the GAC as well as the sand filters. So, this may reduce the cost of the overall treatment process. So, similarly the membrane bioreactors have been applied for the oil contaminated wastewater. So, we can see here that if we are using a membrane bioreactor and if we are using the membrane application that is plane filtration by membrane and when we are using a membrane bioreactor.

So, we can see that the effluent COD here may be only 129 to 131 whereas in membrane application it may be around 373 milligrams per liter in the effluent. Similarly, the oil may be reduced to around 0.036 to 0.35 milligram per liter whereas, it may be around 1 milligram per liter in case of the simple membrane application. And COD removal efficiency is nearly 97 percent and oil removal efficiency are nearly 99.9 percent in comparison to the efficiency of the removal of COD by membrane application only that is around 85.6 percent only whereas the oil removal is only 99.2 percent. So, we can see that the membrane bioreactor can be highly beneficial for an industry where the effluent is being produced which is contaminated by oil. Similarly, we can have another example where olive mill wastewater can be treated by using the membrane bioreactor.

For example, you can see here that during the electrochemical process the phenol input is nearly 1520 and the removal of phenol that been achieved is nearly greater than 90 percent and COD removal achieved is nearly 35 to 15 percent. Similarly, in the electro coagulation also only 52 percent of COD removal is reached. Similarly, for the USB reactor nearly 70 percent of the COD reduction takes place and similarly in CAC reactors we are having nearly 70 to 74 percent of removal of the phenol whereas 30 to 65 percent of the COD removal takes place. Similarly, if we apply the fungal lactase in that case also it is very low and similarly if we are having Pleurotus as the applied for the removal of the olive mill wastewater. So, it can be only nearly 69 to 76 percent of phenol can be removed whereas in case of membrane bioreactor we can achieve efficiency of greater than 92 percent and similarly the COD removal simultaneously can be reached up to 37 to 81 percent.

So, this is how we can see that the COD removal efficiency not only enhances, but a particular pollutant for example, in this case the phenol so that can be removed effectively by using the membrane bioreactor. So, now we can also have a certain hybrid system which have just now come into existence where we can combine different type of processes and as well as the membrane so that we can reach highly efficient and robust process for the treatment of industrial wastewater. For example, we can see here this is an anaerobic hybrid membrane bioreactor, so it is also called ANHMBR. So, this type of reactor can be used where we can have the suspended growth systems, we can have the attached growth systems, and we can have the membrane also attached here so that we can get a high-quality effluent. So, this type of system has been applied for the treatment of synthetic leachate and the leachate is a liquid which is generated from the landfill site which is having a very low pH values, a very high COD values and it is having a lot of concentration of heavy metals into it and such type of leachate can be treated easily by using a hybrid membrane bioreactor.

Hybrid basically means that is we are having the suspended growth systems also; we are having attached growth systems also as well as we are having the membrane process involved here. The treated wastewater passes through the membrane, so it produces a very high-quality effluent. So, we can see here that this is a upflow system and in the up-flow cyst we are having the sludge blanket, the sludge blanket we are having the suspended growth of the microbes that are taking place and because this is a anaerobic hybrid membrane bioreactor so the gas production is also taking place from here. So, this is the gas production that we take place, the biogas is getting removed and similarly we are having a system here which is having the attached growth systems that is the microbes are growing on a certain media. So, in this case it is a polyurethane foam on which the microbes grow, and they treat the wastewater, and this also leads to the less load on the membrane in the sense that it does not allow the MLVSS to go directly to the membrane and reduces the load of the MLVSS on the membrane.

So, such type of systems is also being used and it has been found that the raw leachate can be treated by such a reactor, and it is having an efficiency more than 80 percent when the raw leachate is being put onto such type of system. So, these systems are quite robust systems that are now being developed and they are in research. So, now there can be certain advantages and disadvantages of the membrane technologies. For example, we are talking here of micro filtration and ultra filtration. So, the advantages are that it can reduce the amount of treatment chemicals that may be involved during the treatment of the water or the wastewater.

So, lot of chemicals may be required during the treatment, it reduces their amount for example, we have talked about the treatment of the textile wastewater in the previous slide. So, there we have reduced the clarifloculator because of the application of the membrane. So, the clarifloculator also requires some types of chemicals that needs to be added which can be replaced by the membrane treatment. So, similarly the smallest space requirements are there. So, it requires a small footprint and because of the membrane.

So, we have already seen that the secondary settling tank may not be required right. Similarly, other filtration units may also not be required. So, this reduces the space requirement of the bioreactors. Similarly, it can also reduce the labor requirement as such type of systems can also be easily automated and they will reduce the staff or the labor that are involved in the management of such type of plants. Nowadays, a new membrane designs are being carried out which may allow lower pressures also.

So, this may reduce the cost of the treatment. Similarly, it can remove number of protagonists, oocysts as well as the Hellman's ova. They can be removed by such type of systems and similarly, they can also remove the bacteria and the viruses during the micro filtration and ultra filtration. But it can also have certain disadvantages also. For example, it uses more electricity that is it is a high energy intensive system.

So, that is why this may be the cost may because of the input of the energy that is required for the operation of this plant. Similarly, it may also need the pretreatment so that it can prevent the membrane fouling as you have discussed earlier also. So, membrane fouling increases the cost. So, the pretreatment also basically may be required. So, pretreatment may also increase the cost, but it may reduce the cost in the sense that the membrane fouling will not occur very frequently which will reduce the load on the cleaning as well as it can also reduce the load on the membrane.

Similarly, it requires the residual handling and disposal of the concentrate that is generated from system process. So, this may be one of the disadvantages and it may also require the replacement of membranes which are quite costly. So, this we add to the cost of the operation and maintenance. The scale formation on the membrane is also a very very serious problem which can reduce the flux, and the flux basically declines gradually over time as the scale formation or other foulants are present in the water or the wastewater. So, the flux rate gradually declines, and we have to go for the cleaning right.

It can be physical cleaning that is simply by water, or it can be chemical cleaning. Once the flux declines to such a level that we have to replace the membrane. So, this may be one of the disadvantages of such technique. So, for the RO process also the advantages may be for example, it can remove the dissolved constituents, it can disinfect the treated water as we also seen in the ultra-filtration, it can remove certain targeted compounds like here the NDMA is there this and other related organic compounds. So, they also can be removed by the reverse phosphatides process.

Similarly, we can also remove the natural organic matter which is present in our wastewater or in case of water also. So, this natural organic matter can be easily removed by RO processes. So, disadvantages can be for such type of RO system may work very well on the ground water which is having very low solids, or it can be basically also work on the surface water which are pretreated, or they are having very low solids. So, they also can be treated by using RO process. Similarly, the wastewater effluent can also be treated, but the wastewater should be pretreated before it is taken to the RO process.

Similarly, there is a lack of the reliable low-cost method of monitoring performance. For example, when we talk about targeting of certain compounds which are present in the water or wastewater. So, we have to perform a certain high-cost analysis. So, that we can monitor such type of compounds whether they are removed by the system, or they are not removed by the system. So, there is a lack of the low-cost method of monitoring of the performance in such a case.

Similarly, it may also require residual handling and disposal of the concentrate. So, this may again add to the cost and such type of systems they are quite costly not only in the sense of the capital cost, but also during the operation as it requires very high pressure. So, now one of the topics that we are discussing is the disposal of the concentrated waste stream. So, this can be one of the major problems that arises because of the membrane treatment systems. For example, we are having a small facility where water filtration is taking place.

So, it can be blended with the wastewater flows and where it can be treated further and the nano filtration and RO basically concentrates they may contain high amount of hardness, it may contain high amount of heavy metals, it may contain high molecular weight organics which are present, it may contain microorganism and it may also contain hydrogen sulfide gases etcetera and because whatever we have removed from the water or the waste water, so that is concentrated and these type of things now they appear in the concentrated form. So, it is very important that we dispose it off properly, so that no contamination or the environment is not impacted by such disposals. So, for example, if we are having a simple brine solution which is coming out from the treatment by the membrane process, so this can be put into the ocean discharge, but it should be only a concentrated brine solution, but here it should not contain other contaminants. So, that can be put into the ocean directly because the ocean also contains high amount of salt. Similarly, it can be also disposed off to the surface water, it should not contain any other contaminant into it.

The land application of such concentrate can also be done, but it should be having a low concentration of the brine solution, otherwise it may impact the fertility of the soil. Similarly, for small discharges where TDS are not significant, it can be directly put into the wastewater collection systems, it can also be put into the sewer lines, but it should not increase the TDS, the total dissolved solids to a significant level. Similarly, we can also think of the deep well injection where the concentrate may be put to the deeper aquifers right which are not connected by the surface aquifers. So, there also we can put, but again we have to see that the water may not also contain certain type of contaminants into it. And similarly, we can also go for evaporation ponds where large surface area may be required, we can also go for the controlled thermal evaporation where which is again energy intensive process and because it may be the only option that is if temperatures are not very high in the cold climate.

So, we can go for the controlled thermal evaporation of such type of concentrates. So, then there are number of technological advances that are taking place, so that this type of technology that is the treatment of the water or wastewater by using membranes, so it may become feasible. For example, nowadays people are working on a smart membrane where they are searching on self-healing or anti-fouling properties, so that it can enhance the longevity as well as it can reduce the maintenance costs of the membrane bioreactors. So, again the membranes that are being produced for example, if they are self-healing or they are having anti-fouling properties, so they may be costly. So, the cost is a very important factor and now people are working that they can develop the smart membranes at a lower cost.

Similarly, we can also go for nano material integration where the membrane can be incorporated with the nano materials which again can improve their selectivity, it can enhance the permeability, it can also improve the overall performance of such type of membranes. Similarly, the forward osmosis and pressure retarded osmosis are also being tried, so that the energy efficient water treatment can take place, and we can harness the osmotic gradient, and we can go for a feasible water treatment process. And similarly, data analytics and artificial intelligence are also being introduced or included, so that we can go for the real time monitoring, we can go for the control of such systems, we can go for the optimization of the membrane processes, we can improve the efficiency and ultimately, we can reduce the operational cost of membrane processes. So, now let us take one design example.

Question 1:

A brackish water having a TDS concentration of 3000 g/m^3 is to be desalinized using a thin-film composite membrane having a flux rate coefficient k_w of 1.5 X 10^{-6} Sec^{-1} and a mass transfer rate coefficient k_i of 1.8 X 10^{-6} m/s. The product water is to have a TDS of no more than 200 g/m^3. The flowrate is to be 0.010 m^3/s. The net operating pressure(ΔP_a - $\Delta\prod$) will be 2500 kg/m^2.sec. Assume the recovery rate will be 90 percent. Estimate the rejection rate and the concentration of the concentrate stream.

Solution:

The problem involves determination of the membrane area required to produce 0.010 m^3/s of water and the TDS concentration of the permeate. If the permeate TDS concentration Is well below 200 m^3/s ,blending of feed and permeate will reduce the required membrane area.

2. Estimate membrane area using eqn.

$$F_W = K_W(\Delta P_a - \Delta\Pi)$$
$$= (1.5\times10^{-6}\ Sec^{-1})\left(\frac{2500kg}{m^2}\right)$$
$$= 3.75\times10^{-3} kg/m^2 \cdot s$$

$$Q_P = F_W \times A$$

$$A = \frac{\left(\frac{0.010m^3}{s}\right)\left(\frac{10^3 kg}{m^3}\right)}{3.75\times10^{-3} kg/m^2 \cdot s}$$

$$= \mathbf{2667\ m^2}$$

3. Estimate permeate TDS concentration using eqn.

$$F_i = K_i \Delta C_i = \frac{Q_P C_P}{A}$$
$$Q_P C_P = K_i\left(\left[\frac{C_f + C_c}{2}\right] - C_p\right)A$$
Assume $C_c \approx C_f$ and solve for C_p
$$C_p = \frac{K_i A C_f}{Q_P + K_i A}$$
Assume $Q_P = rQ_f$
$$C_p = \frac{(1.8\times10^{-6} m/s)(2667m^2)(3.0\ kg/m^3)}{(0.01)(0.9) + (1.8\times10^{-6} m/s)(2667m^2)}$$
$$= \mathbf{0.152\ kg/m^3}$$

The permeate solute concentration is lower than necessary. It may be possible to reduce the area by blending.

4. Estimate the rejection rate using eqn.

$$R\,(\%) = \frac{C_f - Cp}{C_f} \quad X\,100$$

$$R = \frac{(3.0\text{kg/m}^3 - 0.152\ \text{kg/m}^3)}{3.0\ \text{kg/m}^3} \times 100$$

$$\mathbf{R = 95\%}$$

5. Estimate the concentrate stream TDS using eqn.

$$C_c = \frac{Q_f C_f - Q_p C_p}{Q_c}$$

$$C_c = \frac{(0.1\text{L})(3.0\ \text{kg/m}^3) - (0.9\text{L})(0.152\ \text{kg/m}^3)}{0.1\text{L}}$$

$$\mathbf{C_c = 31.4 kg/m^3}$$

Question. 2:

Determine the silt density index for a proposed feed water from the following test data. If the spiral-wound RO membrane is to be used, will pretreatment be required ?

test run time = 30 min
Initial 500 mL = 2 min
Final 500 mL = 10 min

Solution :

1. Calculate the SDI using Eq.

$$\text{SDI} = \frac{100\,[1 - \left(\frac{ti}{tf}\right)]}{t}$$

$$\text{SDI} = \frac{100\,[1 - \frac{2}{10}]}{30}$$

$$\mathbf{SDI = 2.67}$$

2. Calculate the SDI to the acceptance criteria.

Calculated SDI value of 2.67 is less than 3.0 (see table); therefore , no further pretreatment would be needed normally. As a practical matter, because the SDI value is close to 3.0 it may be prudent to consider some form of pretreatment to prolong the filtration cycle.

Question.3:
Estimate quantity and quality of the waste stream, and the total quantity of water that must be processed, from a reverse osmosis facility that is to produce 4000 m^3/d of water to be used for industrial cooling operations. Assume that both the recovery and rejection rates are equal to 90 percent and that the concentration of the feed stream is $400 g/m^3$

1. **Determine the flow rate of the concentrated waste stream and the total amount of water that must be processed.**

$$\text{Recovery rate, r}\,\% = \frac{Q_f}{Q_p} \times 100 \qquad (1)$$

Qp = Permeate stream flow, kg/s
Q_f = Feed stream flow, kg/s

$$Q_f = Q_P + Q_c \qquad (2)$$

Combining Eqs. (1 & 2):

$$\mathbf{Q_c = \frac{Q_P(1-r)}{r}}$$

Determine the concentrate stream flow rate.

$$Q_c = \frac{(4000 m^3/d)(1-0.9)}{0.9}$$
$$= \mathbf{444\ m^3/d}$$

Determine the total amount of water that must be processed to produce $4000\ m^3/d$ of RO water using eqn. (2), the required amount of water is

$$Q_f = Q_P + Q_c \qquad (2)$$
$$= 4000\frac{m^3}{d} + 444\frac{m^3}{d}$$
$$\boldsymbol{Q_f = 4444\ m^3/d}$$

2. Determine the concentration of the permeate stream. The permeate concentration is obtained by eqn.

$$C_p = C_f(1-R)$$
$$= 400\ g/m^3(1-0.9)$$
$$\mathbf{C_p = 40\ g/m^3}$$

3. Determine the concentration of the concentrated waste stream. The required value is obtained by solving Eq.

$$C_c = \frac{Q_f C_f - Q_p C_p}{Q_c}$$

$$C_c = \frac{(4444\ m^3/d)(400\ g/m^3) - (4000\ m^3/d)(40\ g/m^3)}{444\ m^3/d}$$

$$\mathbf{C_c = 3643\ g/m^3}$$

So, these are the differences that I have used in the during the preparation of these lectures. So, with this we come to the end of the membrane technologies for the wastewater treatment.

Thank you.