Course Name: Industrial Wastewater Treatment

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Week – 11

Lecture 5: Treatment of wastewater produced from pharmaceutical industry

So, welcome back. So, we are in module lecture 5 and we are discussing about the treatment of the wastewater produced from the pharmaceutical industry. So, in this lecture we will be covering the treatment of the pharmaceutical contaminants, and we will cover the methods other than the conventional method that we have discussed in the last lecture. So, we will be talking about the anaerobic treatment for the wastewater containing specific type of the pharmaceutical contaminants. We will talk about the advanced oxidation processes for the treatment of the pharmaceutical wastewater. We will talk about the electrochemical advanced oxidation process for the treatment of the pharmaceutical wastewater.

We will talk about the membrane bioreactor. We will talk about the micro-algal bioremediation methods. We will talk about the constructive wetlands, and we will also talk about the adsorption method for the removal of the pharmaceutical compounds. So, active pharmaceutical contaminants that is APC.

So, they can enter surface water through the various pathways for example, they can be released by the wastewater treatment plants for example, the wastewater treatment plants they may not be able to handle such type of pharmaceutical contaminants coming into the wastewater. So, the conventional treatment plant may not be able to remove these pharmaceuticals, and they may ultimately come to the surface water without treatment and that is why these active pharmaceutical contaminants are now being found in the surface water as well as in the groundwater. Similarly, it can be discharged from the aquaculture facilities where we use a number of antibiotics and other drugs for the aquaculture. It can also come from the runoff from the agricultural fields. It can also basically be coming from the application of the biosolids and manure to the soil.

So, these runoff from the agricultural field as well as the manure so, they may contain certain pharmaceuticals which has come into the animal waste into the manure. So, that basically may leach into the water and that may come into the surface water. So, wastewater treatment plant so, they are significant sources of the pharmaceutical related contaminants and we have already discussed that because of the incomplete treatment because the conventional treatment plants they are not equipped with the facilities for the treatment of the pharmaceuticals so, they may come out in the effluent of the wastewater. Similarly, the other pathways may include the manufacturing sites wherever the drugs are being

manufactured. So, from there it may come into the environment the disposal or of the unused or expired medicines into the sewage or from the hospital discharges also it can come into the surface waters.

The disposal of the treated animal carcasses that can also lead to the induction of the pharmaceutical contaminants into the surface water. The irrigation with the wastewater may also lead to the induction of these pharmaceutical contaminants into the surface water. So, the pharmaceutical sources can be characterized into two parts for example, they can be pointing based sources they can be diffuse based sources. So, when we are having the pharmaceutical contaminants coming into the surface water by a point source like sewage or domestic solid waste or the pharmaceutical industrial waste effluents or biomedical waste so, that basically may lead to a point based source whereas, the diffuse based source may be from the agricultural runoff, urban runoff or from the leakage from the wastewater treatment plant that may lead to the diffuse based sources. And the point-based sources they are easily identified as well as they can be treated easily whereas, the diffuse based sources so, they pose a challenge in the sense that there can be multiple pathways and the concentration in this type of diffuse based contaminants may also change with time.

And that is why it is very important that the strict government regulations are necessary so, that we can safely dispose of the unused or expired medicines and the products which contains pharmaceutical contaminants into the environment. So, the anaerobic treatment can be used, and it has been found that it is most cost-efficient technology for the treatment of the pharmaceutical wastewater, and we can also generate the energy out of it. So, anaerobic digestion can treat the wastewater with high loading rates as well as it can convert a large portion of the biodegradable material into the biogas and similarly the anaerobic treatment is also having a more advantage that it is having low sludge formation in this case. And it has been found that the people have demonstrated that anaerobic bioreactor that is ABR has nearly shown an efficiency of 50 percent COD removal from a pharmaceutical wastewater which contains a very high sulfate content. The sequencing batch reactors have been shown to achieve nearly 80 percent of the COD removal during the pharmaceutical wastewater treatment.

Similarly, the anaerobic suspended film contacts reactors that is ASFCR so, it can achieve nearly 60 to 80 percent reduction in the COD while treating the pharmaceutical wastewater which contains aromatic as well as aliphatic organic chemicals. The fixed film reactor can achieve an efficiency of 76 percent to 98 percent in treatment of a herbal based pharmaceutical wastewater. Fluidized bed reactor can achieve nearly 88.5 percent COD removal in treating the anti-osmotic drug based pharmaceutical effluents. So, we can find that these anaerobic treatment methods can be effectively used for the treatment of the pharmaceutical wastewater.

However, it is necessary that after the anaerobic treatment method we can basically oxidize the effluent and then we can discharge it to the environment. Similarly, it has been shown that the up flow anaerobic fluidized bed so, it can treat a wastewater which contains cephalexin drug into the wastewater. Up flow anaerobic filter UAF so, it has been shown to achieve nearly 65 percent reduction of the COD and which is being produced from a chemical synthesis based pharmaceutical wastewater treatment plant. Sequencing batch bio filters that are SBB integrating anaerobic and aerobic conditions so, it has demonstrated an efficiency of 95 to 97 percent in treating the pharmaceutical wastewater. So, this means that the pharmaceutical wastewater if it is treated by a combination of anaerobic and aerobic conditions so, it can lead to the very high removal efficiency.

A combined system of anaerobic by field reactor that is ABR followed by the biofilm airlift suspension reactor so, it has also been used for the treatment of the pharmaceutical wastewater. So, the advanced oxidation processes can also be used for the treatment of the wastewater which contains the pharmaceutical contaminants. So, it has been shown that the ozonation is quite effective in removing the antibiotics from the wastewater and similarly it has also been shown that UV-H2O2 or H2O2 processes can basically lead to the degradation of acetaminophen from the wastewater. Similarly, phyton and the photo-phyton reactions and also been research has also been shown to remove the drugs like penicillin and diclofenac from the wastewater. The solar ferrioxalate induced photo-phyton process so, it can also be used for the treatment of the pharmaceutical wastewater, and it has been shown in a pilot plant by using a compound parabolic collector CPC, it was used by Monteagudo in et al in 2013.

So, it can lead to the photo-catalytic degradation of the pharmaceutical contaminants. Similarly, the Della-Flora et al in 2021, they showed that the solar photo-phyton is quite effective in removal of nearly 63% of chloramphenicol and 40% of fluconazole and 54% of flutamide and 79% of gem-5-brasil respectively. Photo-phyton also proves to be a very effective treatment technology for the treatment of various type of pharmaceutical contaminants from the pharmaceutical wastewater. So, we can see here that a compound parabolic collector is used for the treatment of the wastewater which basically contains pharmaceuticals. So, here the solar ferrioxalate photo-catalysis is used for the treatment of the pharmaceutical wastewater.

So, in this case the ferrioxalate can be added in the wastewater and H2O2 may also be added in the wastewater and this basically may be taken to the CPC that is the compound parabolic collector here and in this case the solar radiation may convert this ferrioxalate into the ferrous compounds and later on this ferrous compound can react with the H2O2 to produce dot OH radicals that is the photo-phyton reaction happens and then later on the ferric compounds which are again formed so they can be again reduced to the ferrous forms by the photo-catalysis. So, in this way the photo-phyton reaction can basically lead to the removal of a number of pharmaceutical compounds present in the wastewater. So,

electrochemical advanced oxidation processes can also be used for the treatment of the pharmaceutical wastewater, and they have received quite attention in the recent times and EOAPs that is a electrochemical advanced oxidation processes can lead to the in-situ generation of the oxidants like dot OH radicals can be generated from here and H2O2 can be generated and the active oxygen radicals can be generated. So, we do not have to add any additional chemicals like H2O2, and they are generated in-situ during the electrochemical oxidation process and that can lead to the oxidation of the pharmaceutical compounds. So, here in this case the current supply will basically affect the advanced oxidation process and it can lead to the reduction or oxidation of the organic compounds at the anode and the cathode which are present in the electrochemical reactors and it can lead to the conversion of the pharmaceutical contaminants either into the carbon dioxide in water that is completely mineralized or it can be basically be converted into smaller compounds which are biodegradable in nature.

So, we can have two types of oxidation mechanism in this case we can have the electrochemical conversion where the organic pollutant may be converted into intermediate byproducts, and they may not be completely mineralized. For example, here in this case the oxidation of water may lead to the dot OH radical which are adsorbed, and they are oxidized further, and this may lead to the formation of the active oxygen species and this active oxygen species may then partially oxidize the pharmaceutical contaminants. So, this is called the electrochemical conversion process whereas in the electrochemical conversion process the pollutants they are converted into dehydrated or hydroxylated derivatives and then they are totally mineralized, and they form water and carbon dioxide. For example, in this case the water may be oxidized to dot OH radicals and these dots OH radicals then basically are not oxidized further, and they are physically adsorbed onto the anode material, and they may lead to the complete mineralization of the pharmaceutical compounds. So, the electrochemical advanced oxidation process may take place through two processes either it can take to the direct electron transfer process, or it can occur through the oxidation with the radical species which are produced from the indirect mechanism.

For example, in the direct mechanism pharmaceutical compounds they are oxidized by the transfer of the electrons to the electrode so that is the anode, and they may be partially converted to the intermediates or they can be completely mineralized in this case and by the transfer of the electrons to the electrode. So, this is referred as the direct electron transfer process whereas it is possible that the number of species so they can be converted into the active radicals for example here the water can be oxidized to dot OH radical oxygen can be converted to H2O2 or the chloride ions present in the water basically or the wastewater it may be converted to chlorine it may be converted to chloride ions it may be converted to chlorate. So, these species can lead to the degradation of the pharmaceutical compounds. So, we can have two types of anodes here in this case of the electrochemical advanced oxidation processes for example we can have the active anodes which are made

up of noble metals oxides for example ruthenium oxide, iridium oxide, platinum or carbon basically so they may act as active anodes. So, in case of the active anodes the water is initially oxidized to dot OH radicals and this may be sought on to the anode material.

So, if we are having the active anode so in that case the dot OH radicals will be rapidly oxidized to oxygen species which are covalently bound species to the anode material, and they are chemisorbed and they result in the electrochemical conversion of the pharmaceutical compounds. So, this means that the partial degradation or the intermediate compounds are formed and the pharmaceutical compounds are not completely oxidized in this case whereas in the non-active anodes so the oxygen atom of a dot OH radicals so this is not bounded covalently so it remains fizzy-solved on to the anode surface for example the non-active anodes may be made up of prone dope diamond lead oxide titanium dioxide or tin oxide so they basically may act as a non-active anode. So, in this case as the sorbed hydroxyl radicals so they are not covalently bound so they are very high and non-specific reactivity towards the organic substrate. So, in this case the pharmaceutical compounds they can be completely mineralized, and it yields to the electrochemical combustion of the pharmaceutical compounds. So, the electrochemical oxidation so this may take place by the direct oxidation method or by the indirect oxidation method so in this case in the direct oxidation methods so the metal surface of the anode so it basically the oxidation of the water may take place and it may lead to the formation of the sorbed dot OH radical onto the anode and where basically the pharmaceutical compounds can be oxidized.

So, this results in the direct oxidation then we can also have the indirect oxidation where the ferrous species may be converted to ferric species and it leads to the generation of dot OH radicals the chloride ions may be converted to chlorine species and the chlorine may also be converted to chloride ions then these radicals or then these species so they can result in the oxidation of the compounds. So, this is known as the indirect oxidation process. So, the classic photon is a mix where basically the H2O2 and ferrous are added and this ferrous basically is converted to ferric and dot OH radicals. In the case of the electrochemical oxidation the H2O2 is not supplied from outside and the H2O2 may be generated at the cathode so oxygen at cathode basically it can be reduced to H2O2 and basically this H2O2 may then may lead to the phantoms reaction process. The ferric ions which are generated from the phantoms process so that can be again reduced to ferrous ions at the cathode.

So, this cyclic process continues and it can lead to the very high generation of the dot OH radicals. Similarly, we can also have two types of electrochemical reactors we can have a 2D reactor we are basically we are having two electrodes that is the cathode and the anode and these are responsible for the electrochemical oxidation of pharmaceutical compounds whereas in the 3D electro oxidation system in this case the third electrode is also added which is nothing but the particles of the metals or carbon so they can be suspended in between the two electrodes like anode and the cathode and these particles which are

present are known as the particle electrodes because they are converted into the small electrodes as these particles basically may have different charges on different sides and this may also act as a cathode this may also act as anode and a number of reaction mechanism can happen on these particle electrodes for example the direct oxidation can take place whereas the indirect oxidation can also take place and it can also lead to a number of other processes like electrostatic interactions can happen here and similarly the adsorption process can also happen. So, the mass transfer process basically is also enhanced and as these particle electrodes are present in the bulk liquid so they allow very efficient mass transfer of the contaminants or the pharmaceutical contaminants into these particle electrodes and it can lead to the very high efficiency of the 3D electro oxidation system. So, in the 3D electrode we are having a very large specific surface area because of small size of these particle electrodes if these particle electrodes are porous also so it can increase the surface area to a large extent and which can again impact the oxidation process in a fruitful manner and similarly it can also provide the greater current density because of the large surface area the reaction speed can also increase it can also facilitate the mass transport of the reactants and the products throughout the bulk material. So, that's why nowadays the 3D electrodes are being used for the treatment of a number of pharmaceutical compounds like the antibiotics as well as anti-cancer drugs so they are being treated by using the 3D electrochemical reactors.

So, this EAOPs basically they can lead to the oxidation of the pharmaceutical compounds and these pharmaceutical compounds can either be converted into the carbon dioxide and water if they are completely mineralized or they can also lead to the breakdown of the complex organic molecules into the smaller fragments and this can also lead to the higher accessibility of these smaller organic compounds to the microbial degradation and it can also lead to the reduction in the toxicity as the complex organic molecules may be toxic in nature whereas the daughter products which are produced from the electro chemical oxidation process so they may be not toxic to the microbes and they can be easily accessible to the microbial degradation. So, they can easily metabolize these simpler intermediates and this basically may enhance the biodegradation process. So, that's why it is possible that we can first of all treat the wastewater which contains highly non-biodegradable pharmaceutical compounds by using the advanced oxidation processes like electrochemical advanced oxidation process and later on after the biodegradability of the wastewater is enhanced we can take it to the conventional treatment systems. So, we can see here that different type of electrochemical advanced oxidation processes can take place for example, anodic oxidation can take place where the oxidation takes place at the anodic surface itself. Similarly, the anodic oxidation can take place along with the electro-generated H2O2.

So, the reaction of the anodic oxidation is taking place at the side by side the H2O2 is also getting generated from the cathodic reduction and the generation of the H2O2 may enhance

the generation of the hydroxyl radicals. Similarly, the Electro-Fenton reaction can take place by the reaction of anodic oxidation and H2O2 which is being produced and in this case if we add ferrous salts to it if we are having the iron based electrodes so it can also lead to the Fenton reactions and this Fenton reaction can lead to the generation of ferric and ferric basically can again get reduced to ferrous at the cathode and the oxidation process basically can be enhanced by the production of a higher amount of dot OH radicals. Similarly, the photo electro-Fenton or the solar photoelectron process can also take place by adding the compounds which can be photolyzed easily for example, we can have the ferrioxalate compounds they can basically be converted to ferrous compounds in presence of solar light or UV light and this basically can lead to the higher efficiency of the Fenton process and it can lead to the higher generation of the dot OH radicals. Similarly, the electrochemically active per sulphate can also lead to the generation of the highly reactive sulphate radicals. For example, here in the electrochemical oxidation if the per sulphate is present so this per sulphate can be converted into the sulphate radicals.

So, EOPs basically has been used in combination with the biological treatment process for example, it has been shown that the tetracycline when treated by electro-Fenton process and the sequential batch reactor so it can result in the removal of nearly 86 percent of the TOC as well as 83 percent of mineralization can be achieved by using this process. Similarly, sulphathiazole has been shown to be degraded by using a combination of the electro-Fenton and the bioremediation process and it has been found that it has been quite effective in the mineralization of sulphathiazole. Chloramphenicol basically has been shown to be reduced by using the anodic oxidation process. Nearly 95 percent removal of chloramphenicol has been observed and nearly 35 percent TOC removal has also been achieved during this process. So, it has been shown that Valsartan drug has been degraded by using the photoelectron-Fenton and aerobic treatment method.

So, it has been found that Valsartan was completely degraded, and the TOC removal rate was nearly 80 percent. Similarly, the mechanical hull-based water was shown to be removed by using a biological method combined with the electro-Fenton process and nearly 93 percent of COD removal was observed. Non-steroidal anti-inflammatory drugs like diclofenac, ibuprofen, ketoprofen, naproxen. So, it has been shown to be by using a combined biological and electro-Fenton process and 61 percent removal of ketoprofen, 97 percent removal of diclofenac, 86 percent removal of ibuprofen and 81 percent removal of naproxen has been reported.

Similarly, antibiotic metronidazole. So, it has been removed by using the electro-Fenton and the biodegradation process and the mineralization rate was achieved to be nearly 87.4 percent in this case and the TOC removal rate was nearly 98 percent and the biodegradability was enhanced from nearly 0 to 0.46 by this process. So, all these processes have been tried in the lab scale. So, membrane bioreactors can also be used for the treatment

of the pharmaceutical wastewater and Chang et al in 2008, they reported that 20 cubic meter of the membrane bioreactor was able to treat the pharmaceutical wastewater at an HRT of nearly 140 days and it achieved a COD removal efficiency of 96 percent and BOD removal efficiency of nearly 99 percent.

Mosel et al in 2021, they conducted experiments with ultra filtration membrane bioreactor that is U-MBR, and they found that the efficiency of nearly 82 percent for hydroxyproline, 98 percent for ibuprofen, 95 percent for metformin, 92 percent for Valsartan respectively. So, in this case after the pre-treatment that is after the removal of the grit, after the removal of the solids, after the pre-treatment process, it can be taken to an aeration zone where the aeration of the wastewater containing the pharmaceuticals can be done. Aerobic biological degradation can happen here and later on the membrane can be used for retaining the sludge and so that the sludge retention time may increase and so that a near retention time of nearly 140 days can be achieved here and later on after from here when the pharmaceuticals they are degraded by using such acclimatized microbes. So, then basically the disinfection can be done and the water without the pharmaceutical contaminants can be safely disposed off. Then micro algal bioremediation has also shown promising results for treatment of the pharmaceutical wastewater, also shown promising results for the treatment of the emerging contaminants like pharmaceuticals, like personal care products which are coming into the wastewater.

So, the removal of the pharmaceutical compounds by microalgae, so it may involve number of processes like bio adsorption process, bioaccumulation process, intracellular as well as extracellular biodegradation of the pharmaceutical compounds. So, we can have a number of algal based treatment systems for example, we can have high-rate algal ponds, we can have algal turf scrubbers, we can have rotating algae biofilm photobioreactors, we can have straight tank photobioreactors, we can have flat panel bioreactors, we can have flat panel photobioreactors, we can have tubular photobioreactors and we can have membrane photobioreactors. So, in this case the bio adsorption can happen onto the cell wall components, or it can also happen onto the organic substances which are excreted by the cell in the surrounding environment. So, the adsorption rate will depend upon the chemical structure of the pharmaceutical compounds, it will also depend on the surface area on which the adsorption is happening as well as it will also depend upon the surface chemistry between the pharmaceutical compounds and the adsorbate. For example, in this case the cell wall or the substances excreted by the cell.

So, it has been found that hydrophobic and cationic emerging contaminants, so they are attracted towards the micro algal cell surfaces through the electrostatic interactions while the hydrophilic compounds, so they are they exhibit lower bio adsorption rates. So, it has been found that less than 20 percent adsorption rates were found for six hydrophilic pharmaceutical compounds on a green micro alga and less than 10 percent adsorption rates are found for the hydrophilic pharmaceutical compounds like the hormones, progesterone

as well as nongestural, so by using various species of the algae. So, the modification of the micro algal biomass can lead to the enhanced bio adsorption rates. For example, the 70 percent higher adsorption rate was found for the drug tramadol when the micro algal biomass was modified by using 0.1 normal NaOH. So, after the adsorption we can have the bio-uptake mechanism which happens when the pharmaceutical compounds can basically go enter into the cell wall and where they bind with the intracellular proteins. So, this process can take hours, and it can take days also. The bio-uptake of the pharmaceutical compounds, so it can take place by three major pathways. We can have the passive diffusion which happens because of the concentration gradient which happens because of the higher concentration of the contaminant in the wastewater and lower concentration of the contaminant inside the cell. So, the diffusion can happen from the higher concentration to the lower concentration and this process does not require any energy from outside.

And the this can also be passively diffused, but it may require the assistance of the transporter proteins which are present in the cell membrane, and they can basically lead to the influx of the polar molecules into the cell. Whereas it can also be energy dependent, or we can say the active uptake can also happen which basically here the cell membrane has to spend certain energy, so that this active transport of the pharmaceutical contaminant can happen from the wastewater to the inside the cell. So, we can see here that the pharmaceutical contaminants, so they can either be bio adsorbed onto the cell wall here and which can basically be photolyzed by the direct photolysis or it can basically lead to the volatilization of these compounds. So, these pharmaceutical compounds can also be bounded by the ex-polymeric substances which are produced from the algal cell. Similarly, the intercellular biodegradation can also happen when the compounds can be transported can be up taken by the cells and they can be metabolized to the simpler compounds.

Similarly, the bioaccumulation can also take place if the cell cannot metabolize these compounds. You can have intercellular biodegradation also which basically can happen because of the enzymes which are released from the algal cell, so they can also lead to the formation of the simpler molecules here and the hydrolysis can also lead to the catalysis of the pharmaceutical compounds into the simpler compounds. So, there are number of cases which have been reported for different type of drugs where the different species of the micro algae, so they have been used for the removal of number of pharmaceutical compounds. Here in this case and it has been found that a very high removal efficiencies of nearly 100 percent for ibuprofen and paracetamol has been achieved by using a chlorella-Sorokin Iana species in the anaerobic digester along with the algal bioreactor. And similarly, the adsorption process by C chlorella vulgaris, so it has been shown to nearly remove 100 percent of the metronidazole by adsorption method. Similarly, very high efficiencies have also been shown through a photobioreactor which basically employs the algal species and high-rate algal bonds have also shown to remove very high concentrations of caffeine and ibuprofen, nearly 99 percent removal has been observed. Bubbling column

photobioreactors are not very effective in the removal of the paracetamol that has been studied by various species of the algae. Similarly, the bioaccumulation, bio adsorption or biodegradation of enrofloxacin, it is only reported to be nearly 23 percent removed by using this method. Similarly, the incubation of the triclosan is only leads to removal of nearly 40 percent of the triclosan only. So, the constructive wetlands have also been shown to remove the number of the pharmaceutical contaminants.

So, there can be a number of processes for example, the physical processes, chemical processes and biological interactions so that can happen in a constructed wetland which can happen between the plants which are present in the constructed wetlands, the substrates and the microbes which are present in the constructed wetlands. So, they can play a very crucial role in the removal of the antibiotic. So, here we can see that the wastewater which are laden with the pharmaceutical contaminants and antibiotic-resistant genes. So, they can be subjected to the constructed wetlands. So, here the removal, the biodegradation, the substrate adsorption and plant uptake can take place and this can lead to the removal of the pharmaceutical contaminants, it can lead to the removal of ARGs also and we can get the clean water without the pharmaceutical contaminants and ARGs.

So, the principal microorganisms which are involved which are active in the constructed wetlands so it may include bacteria, it may include actinomycetes, fungi as well as the Some protozoa. So, it has been found that the microbial community which contains bacteria as a major contributor so nearly 94 percent of the reduction of antibiotics have been reported for example, the enrofloxacin as well as tetracycline has been removed up to 94 percent by using the constructed wetlands. So, here the factors like temperature, the presence of the plants, the type of the plants that we are using, the antibiotic concentrations so they all affect the removal processes through the microorganisms which are residing inside the constructed wetlands. So, warm temperature can favor the high activity of the nitrifying bacteria and it can also increase the activity of the protein degrading bacteria and we know that as the temperature increases the kinetics of the degradation also improves so it can lead to the higher reduction ability towards the antibiotics in the constructed wetlands. So, it has also been shown that the vertical subsurface flow constructed wetlands so it can lead to the antibiotic elimination, and it can lead to an efficiency of nearly 70 percent removal.

And the constructed wetlands combined with the microbial fuel cells, so it has been shown for the removal of antibiotics as the antibiotic-resistant genes and it has been shown that nearly 99.1 percent elimination rate has been established by using this combination. However, number of antibiotics such as sulfonamide, macro lactone, chloramphenicol, polyether and beta-lactam need more attention as the removal efficiencies are not as high as the other drugs by using constructed wetlands. So, after this process we can also use number of adsorption processes for the removal of the pharmaceutical contaminants. So,

for example, nowadays number of nanomaterials, the photocatalytic degradation methods, nano-filtration so they are being used for the removal of a number of pharmaceutical contaminants.

So, there can be number of biopolymers and bio compounds which can be used for the treatment of the pharmaceutical contaminants. So, these type of biopolymers or bio compounds may contain a number of functional groups which can enhance the adsorption capacity of certain of these compounds. For example, chitosan and its derivatives so they are highly active biosorbents for removal of the pharmaceutical pollutants from the wastewater. So, this chitosan and its derivatives so they are known for their biodegradability, their biocompatibility, hydrophilicity, non-toxicity, antimicrobial activity, low immunogenicity, inexpensiveness and accessibility and that is why they can be used very efficiently for the removal of the pharmaceutical compounds from the wastewater. The combination of the chitosan along with the metal organic framework so it has also shown a very high adsorption capacity towards the tetracyclic.

The combination of granular activated carbon, ozonation and sand filtration has been shown to remove nearly 87 to 95 percent of the active pharmaceutical ingredients in an experimental setup. Activated carbon has also been shown to remove the lot of emerging contaminants which also contains lot of pharmaceutical and personal care products by using the powdered or as well as the granular activated carbon and nearly 90 percent of these pharmaceuticals and personal care products have been removed by using the adsorption method using the activated carbon. However, the water-soluble contaminants can basically easily break through the granular activated carbon process, and they are basically found in the effluents more rapidly in comparison to the hydrophobic contaminants. There can be a number of technologies which can be used for the treatment of the pharmaceutical contaminants. For example, the ultra-filtration membrane bioreactor has been shown to remove 98 percent of ibuprofen.

Similarly, ultra filtration membrane bioreactors are also shown to remove nearly 95 percent of the metformin from the wastewater. Anaerobic treatment can remove nearly 88 percent of azithromycin whereas the anaerobic treatment can also remove nearly 73 percent of the tetracycline from the wastewater. The advanced biological treatment can have shown to remove nearly 61.3 percent of diclofenac. Biochar has been shown to remove nearly 84 percent of Carbamazepine from the wastewater.

Powdered composite adsorbent has shown to remove nearly 54 percent of ciprofloxacin whereas sulfur diazine has been shown to be removed to nearly 68 percent by a photolysis process. The electrofluorination process has shown nearly 89 percent removal of amoxicillin whereas electro coagulation process has also shown nearly 34 percent of the Carbamazepine removal, and the active resistance process has reported nearly 99.8 percent

removal of triclosan. So, we stop here, and these are the references which we have used for the preparation of this lecture.

So, thank you.