Applied Environmental Microbiology
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Lecture – 45
Drinking Water Microbiology V

Dear students, so today lecture we will study about biological treatment of drinking water, which is basically an addition to the conventional drinking water treatment. So, that even the trace nutrients and even the trace contaminants are removed, now biological treatment of drinking water is tricky because as a name suggests we require microbes to eat the contaminants, but remember microbes do not like to grow in environment where there is not sufficient nutrient for them. And in drinking water we cannot provide microbes, the electron donors and the electron acceptors at a very high concentration.

Which actually makes biological treatment of drinking water little tricky, but they are ways around it, which we have used and we will see in the lecture today how we can biologically tree drinking water despite the limitation of its oligotrophic environment. So, let us start, so dear students as we talked about last time and we even we I introduced to you the considerations for biological drinking water treatment.

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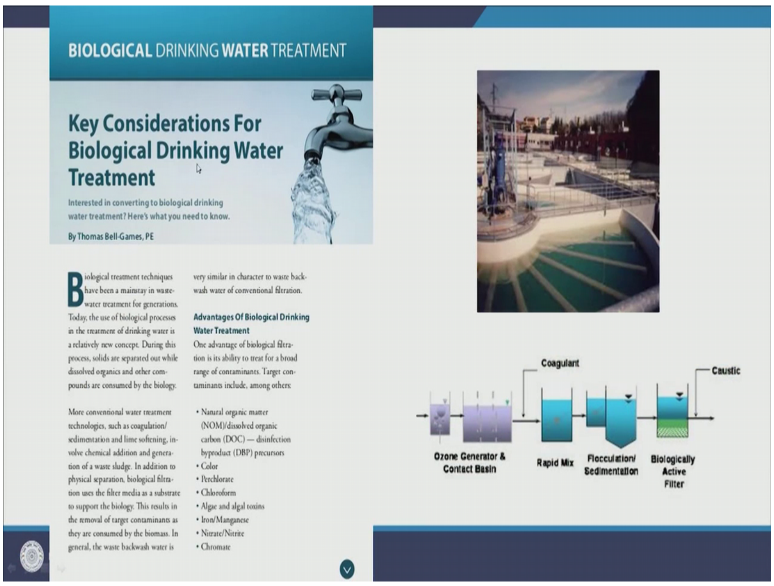

There are many advantages with biological drinking water treatment, first is that we get rid of natural organic matter and thus we have nothing in our water that will produce disinfection byproducts, and I must mention the DBPs or disinfection byproducts are neither good for environment no good for public health.

So, we definitely do not want them in our drinking water and how are they formed when the disinfectant the residual disinfectant interacts with the natural organic matter, it reacts and it forms DBPs we also get rid of color perchlorate chloroform other algal toxin which are usually have pretty good amount of toxicity and iron manganese nitrate and chromate.

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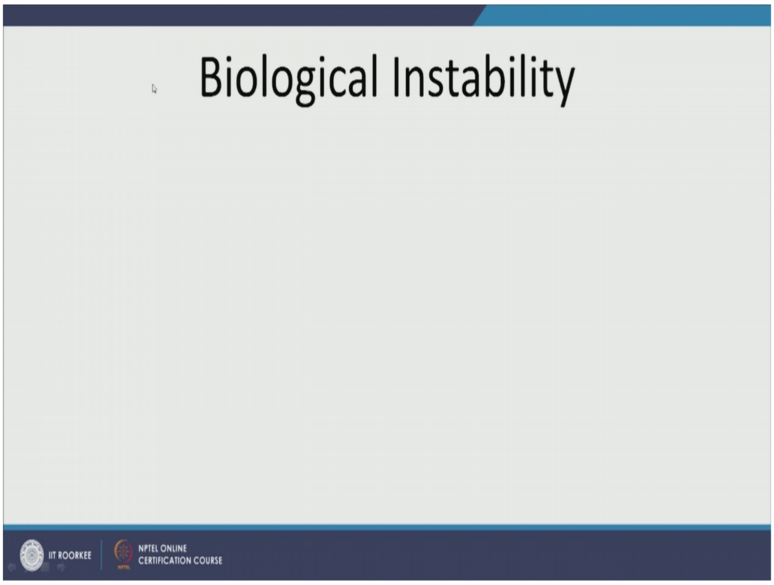

So, let us look at why drinking water has a scope for biological treatment, it is because drinking water has biological instability which implies there are things in drinking water that upon interaction with microbes or biological activities will decay. So, that is instability part in biological instability.

So, what are these it has valid biodegradable organic matter. So, it has things in it that can be eaten by microbes and thus will change the chemistry of drinking water, it has ammonia, nitrate, ferrous, manganese, sulfide. Now among these some of them my electron donor some of them as are electron acceptors and I want you to pause this video here take a moment and try to identify, which of these here ammonia, nitrate, nitrite, iron manganese and sulfide will be electron donors and which will be electron acceptors briefly I can tell you.

So, I hope you have figured out which of these are electron donors which of these electron acceptors, it is pretty easy something is highly reduced like ammonia, then it will be electron donor our iron sulfide, but if something is highly oxidized then it would be electron acceptor.

Now, we also get many metals of upon courage corrosion. So, once water has reached the drinking water distribution system then corrosion gives metals in oxidized state to drinking water, where the reduction can happen now all of these contribute to microbial growth they can be the useless electron acceptor or electron donor, and thus we have we will have biological activity in drinking water system.

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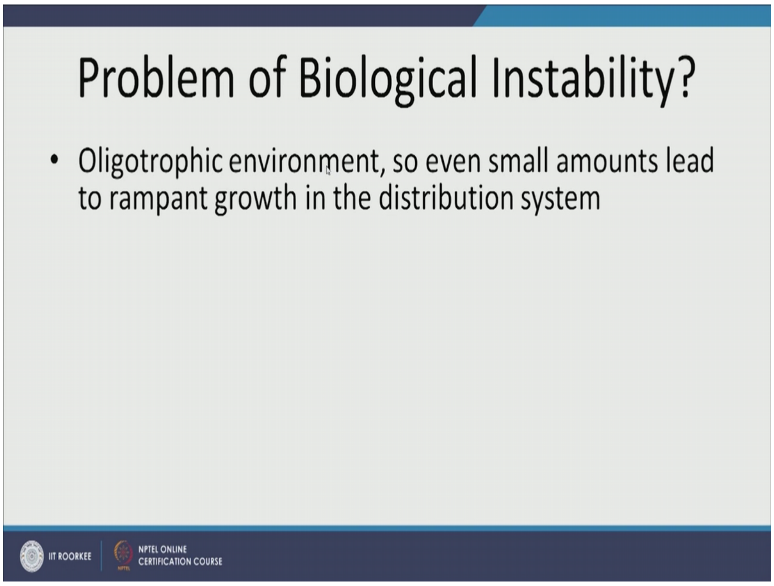

So, what is the problem with this biological instability, well we should understand this that drinking water is an oligotrophic environment, which means that there not enough nutrients oligos means less food is less everything is less.

So, even if we gave little bit amount of food, little bit amount of electron acceptor and donor the microbes will grow as fast as they can, because it is almost a do or die situation for them, you get food you use it and the other thing is when this happens when microbes consume whatever is available to them, we have an increase in heterotrophic plate count.

Which is microbes that can consume different kinds of organic matter they increase in drinking water, and this also overall this biological and chemical activity will result in to taste and odour ratio.

So, the taste will get spoiled the if the water might start smelling, and then we might also have production of nitride which is very bad because it might cause blue baby syndrome, and because heterotrophic red crowned is increasing which is another way of saying the heterotrophic bacteria are increasing.

What will they do when they eat food; they will consume oxygen in the drinking water thus the do of the water reduces. And this is very beautiful and important that the microbial activity actually induces encourages corrosion. So, notice here the corrosion on corrosion the pipes will give microbes, some metals that they can use metabolize and get energy from and on the other hand the corrosion also gives microbes attachment surface for them to stick to then microbes they actually, via galvanic corrosion trout they corrode the pipe material.

Thus they feed each other both the microbial growth in drinking water distribution system and corrosion, thus it is really important to get rid of biological instability. So, we cannot have the rampant growth in distribution system in the first place before we have extensive damage in our pipes. So, let us look at biodegradable organic matter where does it come from.

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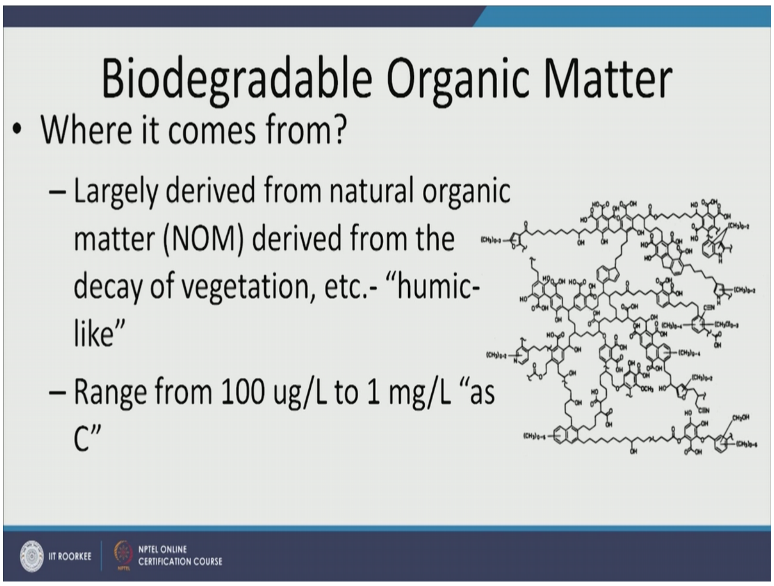

Its largely derived from natural organic matter, and these are the ones that do not are not removed during conventional drinking water treatment processes, and they can range anywhere from certain microgram per liter to milligram per liter as carbon. So, very trace amount or they can have substantial amount.

So, this is one of the picture of humic acid, now remember this is humic acid is only one of the natural organic matter, natural organic matter is basically organic matter in nature that we are not able to characterize because their, their chemistry their structure is very complex. So, it is really how to measure them. So, we have a shortcut we convert everything into how much carbon is present and that is how we measure them.

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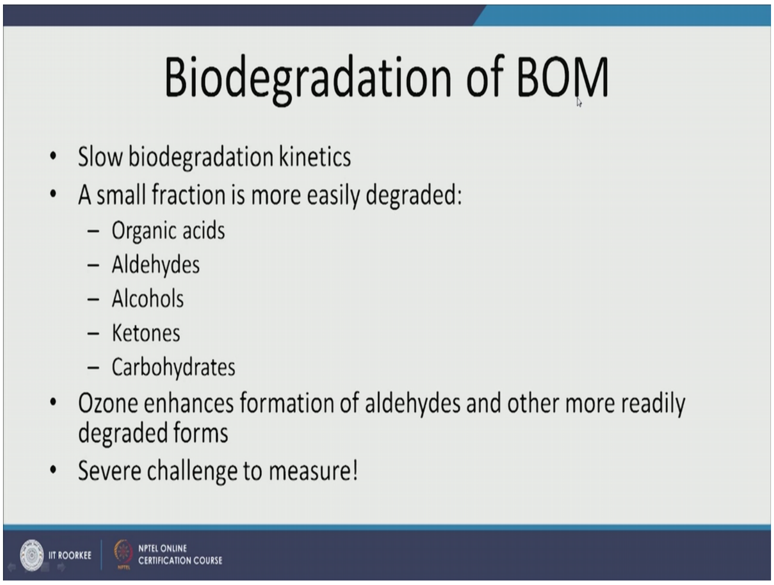

Now bio degradation of biodegradable organic matter, because this is the organic matter that is that has really complex structure like this usually aromatic. And whatever could degrade easily has already degraded we are left with very slow degrading balm biodegradable organic matter thus the kinetics of degradation is very slow, but there is still a certain fraction that will be degraded very fast and here is a list of what will be degraded really fast.

So, how can we enhance the speed of very slowly degrading biodegradable organic matter? So, coming back to this picture look here it is there are so many aromatic rings in it, and most of them are benzene likes earrings or naphthalene, like rings and they, they are very stable and very resistant to degradation by microbes. So, what we do is we find a way to break the structure apart into simpler compounds that are faster to degrade. So, what 1 of the most successful technique for this is ozonation?

So, we ozonate the water and the norm natural organic matter degrades into simpler compounds that microbes can degrade fast usually it encourages formation of aldehydes and other organic compounds, but here is the problem natural organic matter is very difficult to quantify. So, we do not know how much resonation we should do and remember ozonation is pretty expensive a process.

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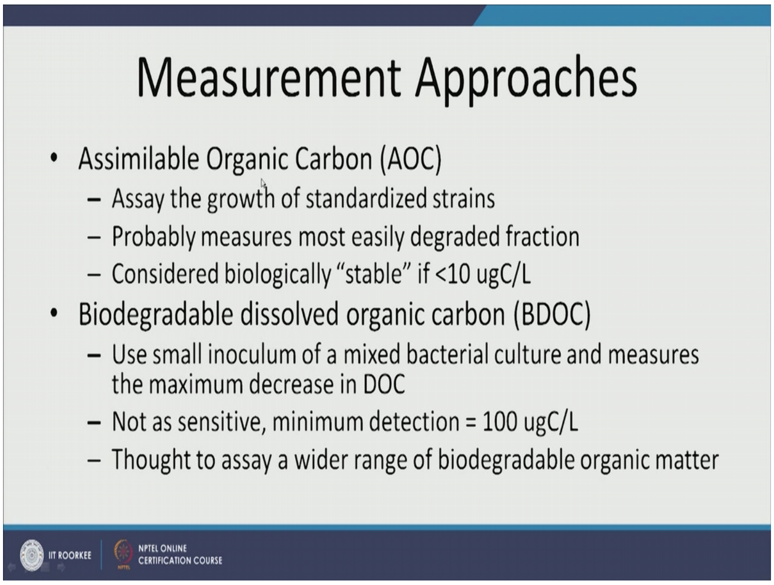

So, how can we measure natural organic matter there are two basic ways that we are currently using well there are others for example, in my lab we use UV spectrophotometer to see the to see how much it is present and to get an idea of what kind of natural organic matter is present, but it has a lot of limitations the other is we calculate amount of assimilable organic, carbon assimilable as the name suggests is the amount of organic carbon, that microbes can assimilate which is basically saying they can use it as a carbon source to make their structure to make their body.

So, whatever they can utilize and make part of the cell is assimilable organic carbon, and there is a standardized way of doing it we have certain strains that we have identified, they are put into the water and we measure how much of assimilable organic carbon is present. Here is a limitation it probably only measures the AOC or assimilable organic carbon that is easy to degrade.

So, if you remember here there are certain parts of by biodegradable organic matter in drinking water, which are easy to degrade most likely these microbes only degrade and consume this easy to degrade for parts of water. And that is how they increase their biomass, and if we notice that AOC is less than 10 microgram carbon per liter of carbon per liter then we say the water is biologically stable which means we should not expect rampant microbial growth in drinking water.

The other is biodegradable dissolved organic carbon. So, what we do here is we have a mixed bacterial culture and we inoculate the drinking water with that culture and we measure how doc changes, or dissolved organic carbon changes. It is not very sensitive minimum detection is 100 microgram carbon per liter, and notice here we cannot tell if it is stable we can only tell how unstable it is, and this is a very beautiful and helpful compared to AOC because it tells us about a wider range of biodegradable organic material and not just the easily degradable portion.

So, let us look at biological treatment now. So, the point of biological treatment is that within drinking water treatment plant itself we want to get rid of all biological instability. So, by the time the water reaches the water distribution system there is no scope for corrosion there is no scope for by a growth of heterotrophic plate count or heterotrophic bacteria, and thereby there is no scope for having pathogens in our drinking water or having our pipes corroded and destroyed.

And what is the alternative to this if we do not do biological treatment of drinking water the alternative is chlorination heavily coordinating the water. Now in one of the previous lectures I have mentioned how in December 20 15, January 20 16, there was a major outbreak of jaundice in Shimla. And thousands of people fell sick I mean officially some 2 3 nearly 3000 people were hospitalized and data is not present for other people. So, we suspect a lot more than 3000 people were sick, but we do not know well. So, in Shimla you know the jaundice was found out that it is hepatitis e virus which is waterborne pathogens as you remember from a previous lecture.

In order to safeguard the public health the amount of chlorine in the drinking water treatment plant, in water storage tanks, and even in the effluent of stp stevis treatment plant was upped. So, they took the heavy chlorination approach to removing biological instability, there severe disadvantages with heavy coordination. First of all remember that if you are not removing the biological instability, you still have lot of natural organic matter in your water and now you are adding chlorine to it in a very good dose.

So, this chlorine or and the residual disinfectant of chlorine, will react with the natural organic matter and form disinfection by products which is very, very bad for environment and also not very good for public health, the other thing is the chlorine itself is not good for public health in in long run it can cause cancer and many other ailments. So, thus we really do not want to switch to the over coordination approach and we want to look at biological removal approach instead, and in this slide I have the phrase called chemical warfare can everybody.

And have, so my disinfectant that there is no scope for pathogens to grow in drinking water system, now note here that when we are over chlorinating we are not only killing the microbes or chemical warfare against microbes, that we know are present in the water at the time of chlorination, but we have lot of chlorine residual disinfectant left when it when the water goes to what a distribution network. And so if there is any pathogen that ingresses or intrudes the water distribution network to a port, then that should also go and when it when it comes in contact with the residual disinfectant it should die.

However there are other beautiful things happening that people talking on offer later lectures when we talk about biofilms. So, there are these protective niches in micro environments and even big environments at times within what a distribution network, where microbes can be protected from access to chlorine and other disinfectants. So, no matter how much we up the level of a disinfectant microbe can always find a safe space in water distribution network.

So, we are very clever and we launched a chemical warfare against microbes they are clever, and they find safe places to hide until they are in good population and the disinfectant level is just enough for them to go out and infect public. So, that is why let us consider the approach of biological treatment of drinking, water where we can eliminate the electron donors. And some of the common features are biofilms we can use biofilms in our drinking water treatment, which can capture the electron donors from the water, and utilize them the other is aerobic processes, but there is a problem with aerobic processes the aerobic process works in a similar fashion as activated sludge process and base water treatment plant where we aerate the water.

So, we are encouraging aerobic microbes to grow and if you remember aerobic microbes grow fastest, because they use oxygen as electron acceptor and that is the best electron acceptor we have on earth for life. So, we increase the amount of aerobic microbes and we hope that they will consume all the biodegradable organic material; however, in extreme cases you know when we do not have enough oxygen and remember aeration is a very expensive step we might lead into septic conditions. So, a water is stink foul; however.

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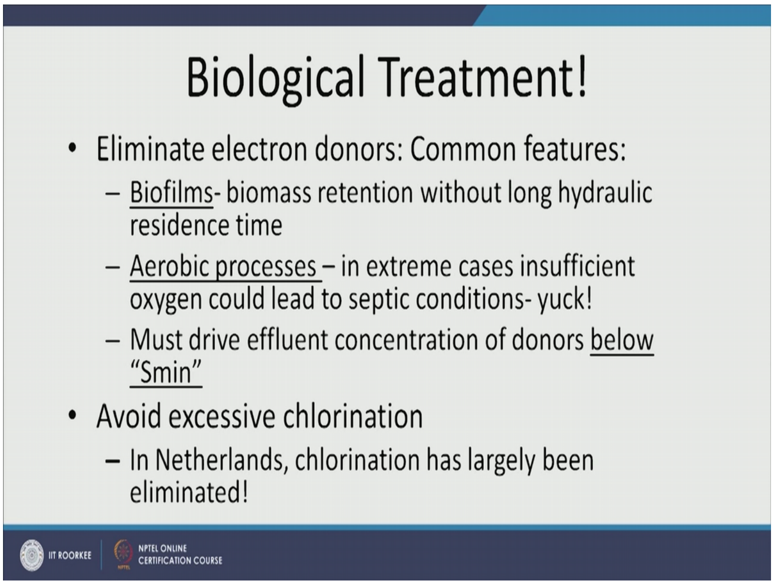

The other thing is we must be able to drive the efferent concentration of donors below Smin. So, S I substrate minus minimum the minimum amount of substrate required for microbes to grow in water distribution network. So, this has to be really rigorous and the other thing is you want to avoid excessive chlorination for the reasons I mentioned earlier to in this lecture, and look there is a country that has almost done it, Netherland is almost eliminated chlorination completely and it. So, happens in India chlorination is rampant.

Every drinking water treatment plant, every wastewater treatment plant chlorinate, chlorinate, chlorinate, and if there is an outbreak over chlorinate, over chlorinate, over chlorinate. In fact, even it is no outbreak from a precautionary measure if it is rainy season we will over chlorinate the water. So, there is lot a scope of improvement in India and under Indian circumstances, but at the same time because microbes can be.

So, site specific and so distinct and the conditions in India and the way we operate our water distribution network is so different it is very important to first to indigenous research and find out how our microbes growing, how are they persisting in resisting this infection, and then decide what is the good approach for India well that is the work I am doing by the way, all right now let us look at biofilm pretreatment.

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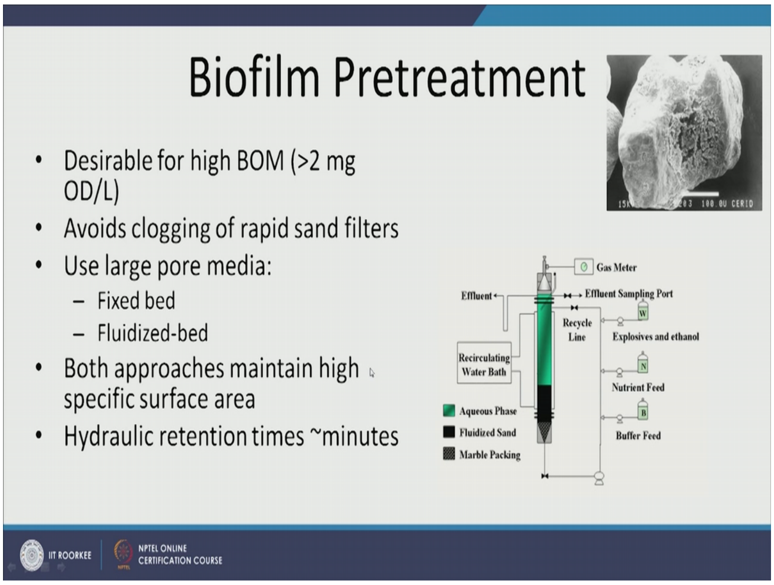

So, this is member of biofilm and this is a typical biofilm setup, and it works really well when you have quite good amount of a biodegradable organic matter. So, very if, so biofilm treatment basically you have a biofilm, and you pass your water through it and when the water passes through it, biofilm they capture all nutrients and degrade it is really nice because in our conventional drinking water system, if we have you know we have to a kind of sand filters rapid and slow. So, it will avoid clogging of the rapid sand filter because it has already eaten up all the organics, and there is no scope for microbes to grow.

We usually use large pore media it can be fixed bed and fluidized bed here we have fluidized sand by the way fluidized bed, and both approaches have they have a similar principle that is high surface area for microbes to attach and grow and to come in contact with water. So, look here the cylinder here is really thin in its diameter, so cross sectional area is not very large, but now we have fluidized sand.

So, when the water is sent it floats up and every sand particle lends its surface area for biochemistry grow, and for a to come in contact with water and degrade the surface it is very, very high very high compared to cross sectional area, and the hydraulic and its really quick process because of the immense high surface area. So, hydraulic retention time is just minute’s really quick process.

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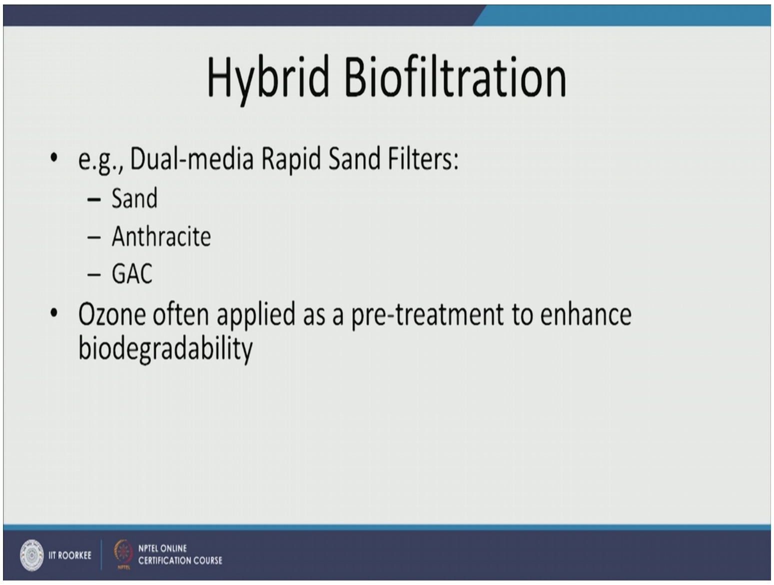

Now, let us look at hybrid bio filtration, this is where when we have dual media rapid sand filters, we can use two media sand anthracite or GAC, activated charcoal and often ozone is used as a pretreatment. So, we use a ozone to degrade the nom natural organic manner and enhance the biodegradability or the ease with which microbes can consume the organics and then we pass them through doing me a rapid sand filter.

And this is applicable when biodegradable organic matter is low, less than 1 milligram bod l per liter and, but here is a problem if it is high and you are still using it lets say there is a rainy season and now we have a lot of natural organic matter, in our water then it will clog your it will, will cause lot of head loss in rapid sand filter and thus it would be better in that case to go for biofilm pretreatment.

Now, let us look at slow sand filtration, in this case we of coal as a name suggest the filtration process is slower. So, infiltration rate is lower than that of rapid sand filter hair loss is not a big concern and the hydraulic loading is less than rapid sand filter because the infiltration rate is slow it, but the advantages that does not require a lot of the area and the biological activity is concentrated to a small region its has a fancy word schmutzdecke.

So, you remember the spelling it will come in your test and when we notice that this biological mat microbial mat of schmutzdecke has grown enough we can scrape it off. So, we know it has grown enough in our head loss increases beyond what we wanted to be then we can scrape it off and allow the microbes to re grow, so how it works is this.

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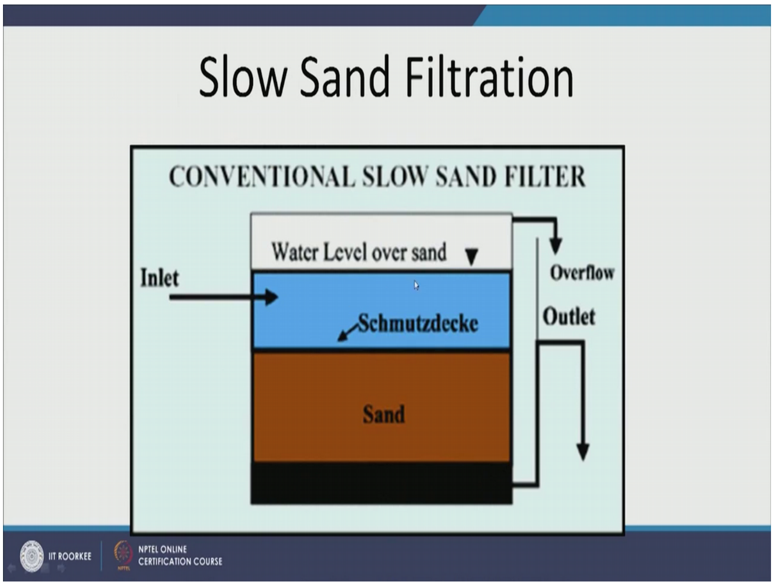

We have indent and here we have our schmutzdecke where microbes are growing and this is a biofilm by the way. So, this is biomass and this bio this mess of biomass consumes the nutrients and then you have you go through your rapids on filter and you have outlet here. So, this removes all the natural organic matter it passes through the sand. So, it is an microbes will get stuck, so there is no scope that you will have microbes here, and then just go ahead and do whatever you need to do and when this become too thick, the schmutzdecke layer then you can scrape it off and allow microbes to regenerate. So, this is a really, really helpful conventional slow sand filter.

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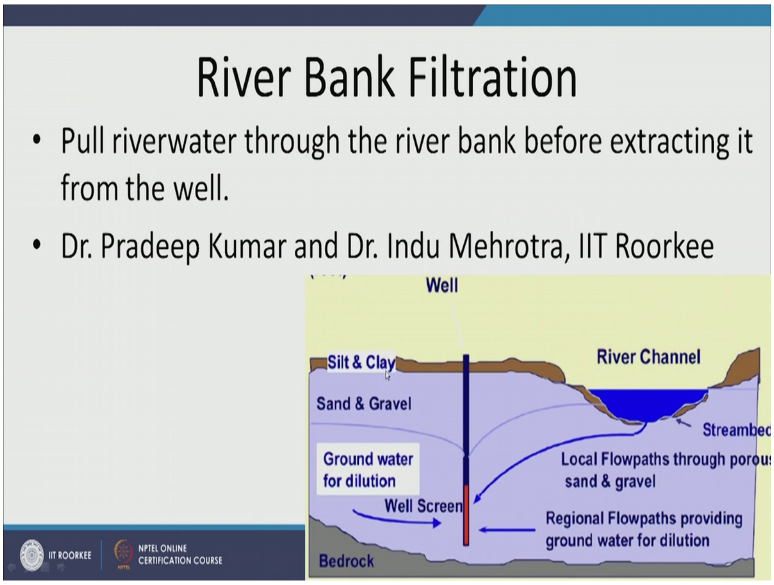

The other is riverbank filtration and I must say at the very onset there I am very fortunate that I work in an institute, where we have two stalwarts who have worked a lot on riverbanks filtration in India.

In fact, for those of you who are familiar with North India and well I am more familiar with North India, and I know that there are plenty of riverbank filtration setups across Himalaya, lower Himalayas and in Uttarakhand. So, doctor Pradeep and doctor Indu mehrotra from IIT roorkee have worked immensely on this, the process of riverbank filtration works this way that if you are taking water from a river then instead of directly taking it from the river, pull it from the riverbank.

So, we make a well in the river bank, so this is a river by the way this is the river alrighty and here we draw a deep well and we allow the water to flow in through the soil. So, the soil is doing the process of slow sand filtration and in the soil we had a lot of microbes that grow and filter and clean the water.

So, by the time the water reaches the well, the quality of water is really good and we have some groundwater here also by the way which will dilute further. So, this quality improves better because groundwater is typically pretty clean and, but it can have other limitations and then we draw the water from the well as our raw or drinking water source.

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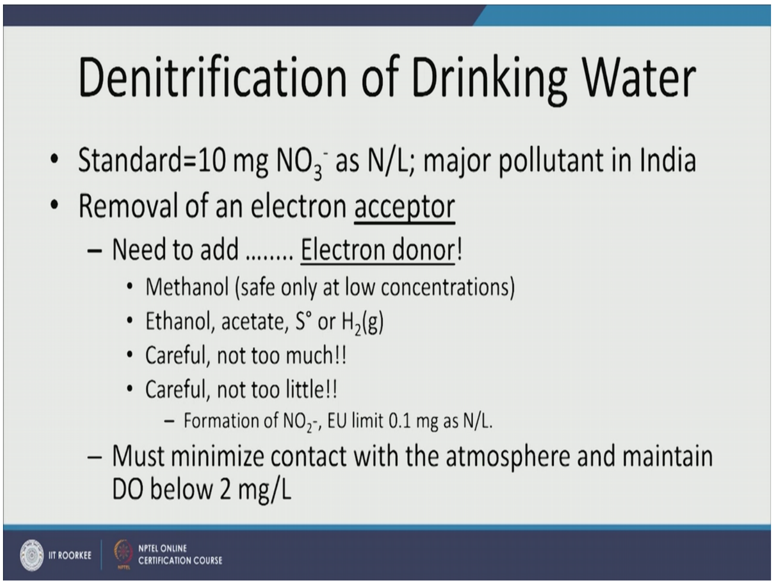

Now let us come to the next challenge that we have. So, we have done rapid filtration now we have a big challenge in our country and elsewhere too of denitrifying drinking water, and if we do not denitrify we come in completely denitrify then we have health problems.

And particularly India is 1 of the regions where we have big issue because we have lot of nitrogen in our water, a lot of nitrogen in our soil and definitely it has increased after the green revolutions when we increased the utilization of fastest of fertilizers, the standard is that ten milligram of nitrate as nitrogen per liter and we do not in India its a major pollutant, we are still working on how to denitrify in drinking water.

Now, we are trying to remove an electron acceptor you denitrifying. So, they trying to remove nitrate, so you need to have electron donor to it remove electron acceptor we need electron donor which can do the redox chemistry and get away, and other hand if you want to remove electron donor like petroleum then you need to add electron acceptor like oxygen sulfate or nitrate and.

So, that they can degrade and go away, so we need to add electron acceptor, now what are the options that we have for electron acceptor one of the options that we have is methanol, but it is an issue with methanol its only safe at lower concentration, and I must say that methanol has been used successfully across the globe. So, it is not non doable, but we have to be really sure that the methanol we are adding is being used up for the nitrification and hardly any methanol is left in the drinking water.

The other is ethanol, acetate, we can add sulphur, we can add hydrogen gas, and all of these can act as electron donors and denitrify, but here is an issue be very careful do not add too much what will happen if you add too much. So, pause the video and think about it what will happen if you add too much I, I hope that you took your few minutes to figure out what happens when we add too much of electron donor in water, let us say we added twice amount that was required to denitrify.

So, we still have half of the electron donors left now these electron donors will go to our waste water distribution system and there micros will find food. So, there is any microbe lingering in the water distribution system and moment they come in touch with the food, but that is ethanol, methanol, acetate, sulphate, hydrogen, wherever they will grow and then we will have an increase in heterotrophic plate count and the way it works is that lets say I added sulphur as electron donor.

So, a microbe that can use a sulphur as electron donor, then what will happen it will grow and when that microbe dies its cell debris can be food source for other heterotrophic bacteria. So, it is not just microbes that can use sulphur elemental sulphur as electron donor that will grow, but we will have quite diverse microbial communities within the drinking water distribution system.

So, we cannot use too much, we cannot use too little it has to be just the right amount. So, denitrification is challenging and, and the other thing is that we should minimize contact with atmosphere when we are denitrifying, why do you want that? Why do you want to minimize contact with air? Because air has oxygen and we are trying to convert nitrite into nitrogen gas where you can go away we are trying to do de nitrification, if you bring in oxygen into the picture microbes will prefer to use oxygen as electron acceptor, and not nitrate remember, aerobic organism, aerobic activity, more energetically advantageous for microbes. And this week you will have a homework on denitrification.

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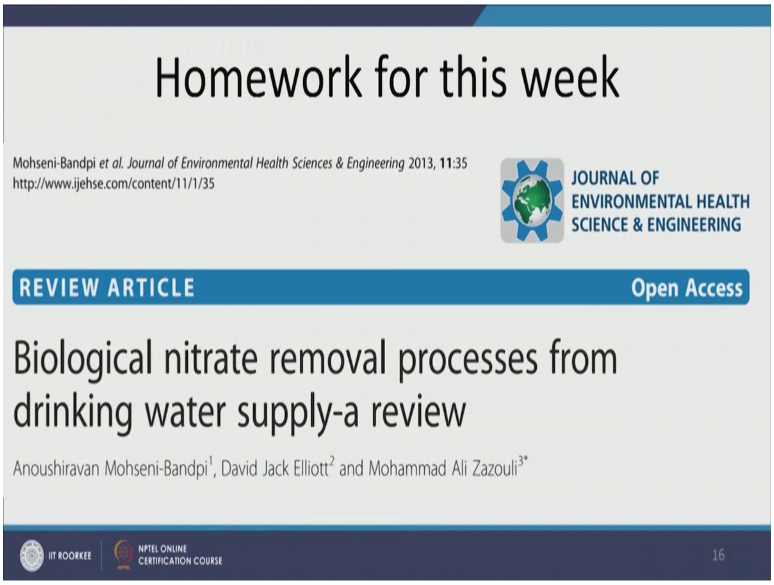

Where, well one of the part of your homework in this way would be reading this review article wonderfully written in 20 13. So, it has been quite some time, but they do a very good job in explaining what denitrification is what are the different electron donor? Electron acceptors that you can use. So, this would be 1 of the reading assignment for you, but just letting you know you have something coming up this week now let us look at some challenges.

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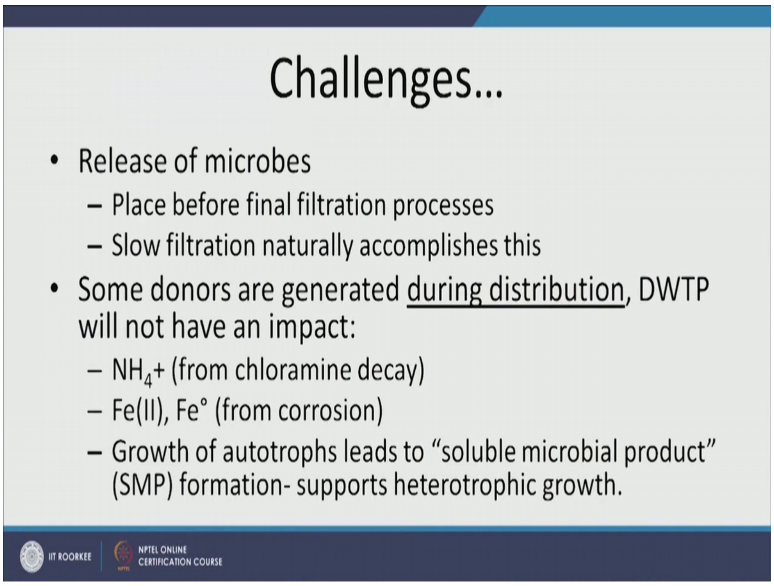

That we have with drinking water or just you know ensuring the quality of drinking water first is release of microbes. So, let us say I have biological treatment that I am doing for my removing that biological instability, whether it is denitrifying or whether it is removing the natural organic matter or biodegradable organic matter. I am increasing the population of microbes, because the way it works is micro I increase the microbes and microbes feed on these electron donors electron acceptors.

And then they grow further and low and behold my water is clean, but there is a possibility that the microbes might escape into drinking water distribution system, and thus might add to the number of bacteria in the in water and usually it happens in slow sand filtration.

So, remember it slow sand filtration here, so sand filter then we had our microbial layer. So, this mat sometimes can allow microbes to escape through slow sand filter and go into water the other thing is sometimes within drinking water distribution system, there are some, some donors that are produced some metabolites that can be utilized by microbes in the distribution system for example.

So, this happens during distribution not during treatment. So, let us say during my drinking water treatment I got rid of natural organic matter, I got rid of nitrate and I got rid of other balance because instability and I am like, I did it I cleaned the water, but now I put my water into drinking water distribution system and there is there are things there their metabolites there that microbes can use to grow.

So, in a way we notice that we do need to treat water to utmost standards in drinking water treatment plant, but that will not ensure that the water is still clean when it moves through the drinking water distribution network for example, let us say I have residual disinfectant in form of chloramine. Now the chloramine might decay and it will give away NH 3 and sorry ammonium ion and that ammonium ion will be left on donor for microbes.

So, microbes can be there who will consume the ammonium and then they will grow. So, even if there were hardly any microbes in the drinking water when it was released from the plant, in wds water distribution system we can have microbial growth the other thing is corrosion. So, there is corrosion happening the metals are leaching or in an oxidized state or reduced state and in either way their microbes who can utilize them, we have iron reducing bacteria we have iron oxidizing bacteria all of them can grow in drinking water system.

The other thing is once there are other microbes that use carbon dioxide. So, there autotrophs they do not even need an organic source of carbon. So, these autotrophs if they couple up with other electron donors and chemical electron donors and electron acceptors when they grow, they create biomass and this biomass when the die can this cell debris can be used by heterotrophs to increase micro population.

So, I have here growth of autotrophs leads to soluble microbial product SNP formation and support heterotrophic growth. So, dear students what are the solutions for those challenges, as of now I would like to tell you that the scientists are still working the engineers are still trying to figure out. How can we stop microbial growth in water distribution network, in India unfortunately there is not a lot not a lot of research that us happening, but internationally there are many global leaders who are working on it, some of them that I can name right away are doctor Marc Edwards, doctor Amy Pruden, in us doctor Amit pinto.

And they are working day and night to ensure that we can, there we have some insight into how we can keep our water clean within water distribution network. So, I think we, I think we finish our presentation today here and in the next lecture and I think this is the end of all water treatment that we have, in the next lectures we will dig into ecosystems. How do microbes grow and utilize other ecosystems that are relevant and important so that is all for today.

Thank you.