Water Quality Management Practices

Prof. Gourav Dhar Bhowmick

Agricultural and Food Engineering Department

Indian Institute of Technology Kharagpur

Week-11

Lecture - 51

Lecture : 51 - Nitrification and Denitrification: Major factors

Hello everyone, welcome to this NPTEL online certification course on Water Quality Management Practices. My name is Gourav, Professor Gourav Dhar Bhowmick. I am from the Department of Agriculture and Food Engineering of Indian Institute of Technology Kharagpur. So, in this particular lecture material we will be discussing about the nitrification and denitrification and what are the major factors that involves with it. And this is a part of the module 11 which is where we will be discussing about the emerging biological processes for nutrient removal and tertiary processes. So, what are the concepts that I will be covering here the start with the nitrification, different stoichiometric equations of nitrification and denitrification, what are the factors that affects the nitrification, denitrification and the factors which affects the denitrification process.

To start with we know that why we need to go for this biological treatment processes because one of the major reason not only the carbonaceous matter, but also to remove the nutrients like majorly the inorganic nutrients like nitrogen and phosphorous. The nitrogen it normally presents in present in the wastewater in the form of nitrite, ammonia, nitrate or organic nitrogen in general and then the cellular biomass as well. This phosphorus it is either in a organic form attached with the carbon based molecules or the inorganic form in dissolved or suspended state. In general in industrial wastewater like the petrochemical, fertilizer, food industries, tannery and these are the these are having high concentration of nitrogen and phosphorous.

There are some amount of waste some type of wastewater like the agricultural runoff where also the there is a chances of this nitrogen and phosphorous level not high, but like you know good enough to you know get it is useful I mean like it is very much beneficial for you to treat it before you actually supply to the surface water bodies or discharge it to the surface water bodies. So, what happened when there is this kind of nutrients present in the wastewater which in a way we call it nutrient, but actually it is can destroy the ecosystem like because what happened because of this kind of nutrients that is available with this water it is it is build up a ecosystem like which will develop the favorable condition for growing the algal growth and which further deteriorates the water quality via the process called eutrophication. We all know about the eutrophication process right. So, during the process of eutrophication the water body gets the ecosystem in the water body gets deteriorated the deolabile goes down and in general the pond will die in very soon with this definitely it showcases with the science of eutrophication. Ammonia in general which is an one of the most reduced form of nitrogen then it is nitrite oxidized to nitrite and then to nitrite causing a reduction in dissolved oxygen of in the water body, but it this and this process is called the nitrification.

So, there are lot of benefits of nitrification in the process because it drastically reduces the ammonia nitrogen present in the wastewater and it further converts into the nitrate which may be which I mean like if it is ok if there are provisions you can actually use that nitrate based wastewater you can simply supply to the concentrated wetland or simply supply to the crop agriculture feed because those agriculture like in general they love the nitrate. So, I mean like the crops they love the nitrate. So, definitely you have to be aware of a lot of the concentration you have to be aware of all the corresponding all the you know all the other pollutants that it presents steel presence in the in this wastewater in that sense, but in general this nitrify this is the process called this is the process what we what we call nitrification. So, where ammonia is normally first it oxidized into the nitrite in the first step and then it go and then it converts into the nitrate in the second step. So, if you can see in the beginning in this figure nitrogen it using the nitrogen fixation process it normally converts into ammonia and this ammonia in the presence of ammonia or oxidizer it converts into nitrate and then nitrate or nitrate oxidizer it converts into nitrate.

So, this nitrate again it you know because of there are different processes known like me like and also we there is another process that also we will be discussing in the coming week I mean like I mean the coming module I mean the coming lecture as well where we will also be discuss about the processes to further oxidize the nitrite into some other nitrogen or other forms. So, in general this is a very commonly achieved goal for the secondary aerobic biological treatment processes where it not only helps the carbonaceous organic matter to be treated carbonaceous organic matter to be get rid of the system, but also it also helps reducing down the pollutant load like the nitrate with the by the with the process of nitrification because of its oxygen demanding process and in the presence of aerobic tank you can actually achieve those things you know. So, similar to this kind of carbonaceous organic matter removal nitrification can also be performed in a suspended as well as in attached growth biological treatment processes right. What are the different type of suspended growth processes that is beneficial for this nitrogen this nitrification process like the activated sludge process you remember we designed it sequential batch reactor or SBR we know about the functionality membrane bioretor we discussed about it that how membrane bioretor works and also. And the next type is the attached growth processes that also we are very much aware of it we know trickling filter we know weaving bed biotium reactor we know rotating biological contactor we know constructed wetland right.

So, these are all the attached growth process all this suspended growth as well as attached growth processes the nitrification can occur because of the presence of the oxygen and if you can maintain the proper BOD to TKN ratio in the system ok. So, in general the nitrification is supported along with the organic matter when there is a BOD to TKN ratio of greater than 4 to 5 it is says to be simultaneous carbonaceous organic matter oxidation and the nitrification process. Most of the existing activated sludge process that we normally maintain try to maintain in try to develop and all the like you know it functions as a the simultaneous organic matter degradation plus oxidation plus nitrification process. There are certain cases where the BOD to TKN ratio is less than 3 that means, the BOD is quite low that means, organic matter presence is quite low. In that case the system itself called as a only nitrification process because there are hardly any biological hardly any organic matter degradation that is needed to be taking place.

So, in general so, this is a separate nitrification process all together where the BOD 5 to TKN ratio is less than 3. So, in suspended growth systems it normally have this adhesion tank we know, it can also have like in a secondary settling tank as you can see in the first figure with the certain return activated sludge recycling system. This is called the single sludge system. In the single sludge system what is happening? So, when there is a chance you know the wastewater needs to be treated simultaneously for organic matter oxidation plus nitrification we have this kind of systems where it is a single sludge system which is quite normal in case of quite normal act it is the design is quite generic for activated sludge process. In the second figure if you see this is called the two sludge system.

In the two sludge system what is happening you see in the beginning what we are doing we are treating the organic matter only ok. It is not possible right like though while you are treating the organic matter there will be some amount of nitrification that is any eventually it will take place. But the majority of the functionality the major function that will that the major dominating process that will be there in the in the in the first stage is the organic matter oxidation. In the second stage there will be the nitrification process where this nitrification process and what is the basic difference between it your with your basic understanding you know that this nitrifying microorganisms it takes longer time for its regenerations and all. And also it needs a very long enough initial start up times as well or acclimatization time as well.

So, for all this reason so, in the first in this kind of in this bottom if you see this two stage sludge two sludge two sludge systems the first one is actually having a lower hydro retention time as well as the sludge retention time. Whereas, in the second case the where the only the nitrification is taking place there the hydro retention time as well as the sludge retention time is quite high we know the reason right because of the slow growing rate of the nitrification nitrifying microorganisms plus the slow start up time of the nitrifying microorganisms. So, in general in attached growth process this heterotopic microorganisms majorly dominates the attached growth surface area. And for combined systems in general that is the reason why BOD load should be kept lower. So, that it can only be used for the BOD removal whereas, in case of separate systems like the two stage one it is a viable option for accomplishing the nitrification in the attached growth process where it which is provided after removal of organic matter in the attached growth or the suspended growth process in the first stage you understand.

So, both the group of microorganisms are in general can be autotropic. However, there are distinctly different from each other in case of nitrification process. The first process which is where the ammonia is getting converted into nitrite in general the nitrosococcus, nitrospira, nitrosolubus or the nitrosorobrio. These are the some of the commonly like known autotropic microorganisms which are capable of oxidizing the ammonia into nitrite. There are similarly we have we know about nitrococcus, we know about nitrospina, we know about the nitroestrus.

So, these are the some of common microorganisms capable of oxidizing the nitrite into nitrite. So, what is the equation that it lies like that it follows like if you see the stoichiometric analysis of it. So, in the beginning in general if you see the overall oxidation overall forget about the overall equation first we will start about the individual ones and the stepwise. So, the beginning the oxidation of ammonia to nitrite see this ammonium ion it is like you know ammonium in the presence of oxygen it converts into nitrite it generates some amount of protons as well as some amount of H 2 O. Then in the follow up stage this nitrite converts into nitrite in the presence of oxygen again.

So, all together if you see there are two number of ammonium ion in the presence of four like you know molecules of like say like four number of oxygen molecules. So, like you know it converts into two number of nitrate molecules. So, I mean like in general nitrate compounds, I mean if you see in this case what is happening here. So, overall nitrification process it is like you know 2 NH 4 plus 4 O 2 equal to like you know it obviously, arrow it with the arrow if you see like 2 NO 3 negative plus 4 H plus plus 2 H 2 O. If you divide it by 2 the equation number 3 will be there.

So, in the equation number 3 says like if you divide by 2 all together like you know that is the we all know about this basic chemical thing is so, like chemistry stuff. So, this NH 4 plus plus 2 O 2 it converts into nitrite nitrate plus 2 H plus and plus 2 H 2 O. So, in general if you see the first equation based on the ammonia oxidation to nitrate. So, if you convert this 3 amount of oxygen which is the having a molecular weight of say 32 gram and say like the NH 4 if you calculate it and then if you divide it with it. So, you will see like you know 3.

43 gram of oxygen is required for per gram of ammonia oxidation you understand. So, this is the this is the this is how actually we calculate the amount of oxygen that it requires for the ammonia oxidation to nitrate. The same way nitrite to nitrate that also requires additional 1.14 gram of oxygen all together 4.57 gram of oxygen per gram of nitrogen.

So, you remember this number we have used it in the design of activated sludge process for the IR requirement in the nitrification process. If you remember it we use this 9.57 this particular number quite a lot remember. So, there in the during the design of aerator this the action required for the nitrification process to occur we need with this number to be memorized in your brain. So, that is the thing this 4.

57 gram of oxygen per gram of nitrogen we have to use utilize that we have to supply this much of oxygen ok. Apart from the oxygen requirement it also it is a alkalinity scavenging process per gram of nitrogen for each gram of nitrogen 7.14 gram of alkalinity as calcium carbonate milligram of calcium carbonate per liter is essential ok. So, what is the process what is the system in general the equation how it looks like? So, like 1 ammonium ion plus 2 HCO3 negative plus 2 O2 equal to NO3 negative like 1 nitrate plus 2 number of carbonate and 2 number of H2. So, this process it is a alkalinity scavenging process that means, it reduces the alkalinity ok.

So, you remember this things in terms of suppose in your aerobic reactor you have a ammonium ion. So, initially suppose you have 10 milligram per liter of ammonium ion at the end suppose effluent has 1 milligram per liter of ammonium ion so that means, that there is a reduction of 9 milligram per liter of ammonium ion. From there from the basic very easy calculation you can justify that if you that 9 milligram per liter multiplied by 7.14 that much of alkalinity is reduced from the system. You will see that if suppose initially you have a 100 milligram per liter of alkalinity 100 milligram of say calcium carbonate per liter of alkalinity it will reduce down to say like 37 because why because that 63 is you can easily calculate that 9 gram 9 milligram per liter of a reduction in ammonia multiplied by 7 that much of you see that much of 63.

So, that much milligram of milligram per liter of alkalinity should be reduced from the system should be like you know like eliminated from the system. And your calculation if you do the alkalinity analysis and if you see that yes it is 37 that means, you are sure that the ammonia is successfully converted into your nitrate. So, this is the form of design this engineering design that you can validate your design by having some you know additional the expert analysis and also you can actually validate your data. Suppose if C 5 8 7 O 2 N it is it is a representation of the bacterial cell. So, part of the ammonia nitrogen always integrated into the microbial cell right.

So, because it digested by the microbes and it actually converts into the bacterial biomass. So, due to this assimilation process it is always there is a practical oxygen requirement for nitrification is less than the 4.57 gram of oxygen per gram of nitrogen because some of the ammonia is converted into cellular biomass. So, that you that you are not taking into consideration. So, that is the way that number of oxygen that amount of oxygen is now surplus to you to us.

So, it is better to have a surplus oxygen than the reduced amount of oxygen. So, it is always when we do the calculation it is better to do it with the 4.57 gram per gram of nitrogen there with this value only ok. So, for the designing purpose I mean like the designing the nitrification process the what are the different constituents of the waste water such as the nitrogen concentration available alkalinity available oxygen carbonaceous organic matter and the presence of inhibitory substances are causing a very vital role in in the process performance in the in the nitrification process and all. So, additionally the phosphorus and trace metals are also required for supporting the growth of the nitrifying algorithms.

So, in case your waste water does not have a tiny bit of trace metal or any phosphorus. So, in that case you may have to supplement it along with the in the in the reactor itself. So, that your you are somehow letting the nitrifying microorganisms grow in the system you understand. So, that is how it works ok. Based on the monod kinetics we can easily get an idea about the growth of the nitrifying microorganisms with the with the value mu n.

So, with this which showcases the specific growth rate of nitrifying microorganisms which equal to the mu m n into N by k N plus N. So, there is mu m n is the maximum growth rate of nitrifying microorganisms per day k N represents the half saturation constant capital N is the concentration of ammonium nitrogen and in steady state condition this biomass produced and the quantity of biomass leaving the system is always equal. So, solid retention time we can also estimate by this equation 1 by mu n minus d N. So, this d N is nothing, but it represents the endogenous decay constant for nitrifying microorganisms. So, as easy as that so, amount of microbes that generates per day divided by minus the amount of nitrifying microorganisms that get out of the system.

So, from there you can easily calculate the solid retention time ok. So, in general this d N value is very less for nitrifying microorganisms compared to the heterotopic. The value of this theta c can be easily obtained from this equation and which is like the theoretical value obviously, for the steady state condition like it is for the steady state condition only. So, in this equation in this equation number 7 this the to compensate the change in unknown factors such as the pH, diesel oxygen, ammonia concentration, temperature and other inhibitory substances it is always better to have a factor of safety of around 1.

52 or greater ok. So, the design value of actual design value of theta c if you calculate it at 10 days so, you have to put it at least 15 days ok. So, at least 1.5 times greater than the actual design value considering all the other unknown factors. So, what are the factors that affects the nitrification process? To start with the inhibiting compounds like the amines, proteins, phenols, alcohols, benzenes. So, these are the inhibiting compounds that can if it presents in the wastewater can harm the nitrifying organisms to proliferate.

So, in that case and so, that is something that we need to be aware of. Then the two stage system in the two sludge systems it is always recommended because in that case what will happen in the two sludge systems the first one is for the carbonaceous matter to be degraded, second one is for the nitrification process to occur. In the first process itself if there are some amount of inhibitory substance present it will reduce in the first adhesion tank itself. So, it will reduce the pollutant load or the pathogenic load pathogenic concentration like pathogenic load or the harmful microbes load in the first stage itself. So, in the second stage there will be no issues.

So, optimal range of pH for nitrification is almost 7.5 to 8 and it is significantly affected in the wastewater with pH below 6.8. So, we have to maintain this pH right and we know that it is a alkalinity demanding process we have to maintain the alkalinity we have to maintain certain amount of alkalinity the system as well. So, to elevate the pH in the wastewater external alkalinity is induced in the form of either sodium bicarbonate lime or soda ash ok.

So, in terms of dissolved oxygen concentration. So, we normally have a nitrifying microorganisms which are aerobic microorganisms and a minimum dissolved oxygen concentration of say like 1 milligram per liter is essential for nitrification to proceed. Below this level the oxygen becomes a limiting factor thus reducing the rate of nitrification. And in anaerobic condition this nitrification is totally suppressed this because nitrifying microorganisms cannot survive in that condition. Ammonia concentration, phi ammonia concentration of around 150 milligram per liter it will be inhibitory and for its oxidation process for this ammonia oxidation to nitrite. And ammonia concentration of around 18 milligram per liter will be inhibitory to nitrate oxidation oxidizing battery there are according to some study by Zhang et al.

2018. So, denitrification. So, why do we need to go for denitrification process? To start with like when there are certain norms there are certain regulations that tells that you can you can limit your total nitrogen concentration in your surface water bodies up to this limit up to this level up to this value right. So, in order to maintain those values in order to maintain those certain regulations and the rules that is prevailing in your particular in your country or suppose in India its central pollution control board or national green tribunal. So, they have maintained they have to they have mentioned that this is the value that above which it can be toxic to the subsequent ecosystem and all. So, we have to maintain the in order to maintain those value you have to you may have to go for further nitrate further removal of nitrate from the system. So, the further removal of nitrate from the systems it can only be done not only be done I mean like say majorly it has been done by the process called denitrification where the nitrite nitrate is converted into dinitrogen or the nitrogen gas ok.

So, this process I mean like this process obviously, it is required because the nitrate it can also cause the eutrophication and any any cases the nitrate concentration more than 45 milligram per liter it may be unsuitable for drinking even in case of groundwater in the groundwater as well. So, basically the nitrification is the process where the reduction of nitrate to nitric oxide, then the nitrous oxide then finally, to the nitrogen gas using the microorganisms it occurs it like that that is how it occurs. So, in general they have this two mechanisms first one is the via the assimilation process what is happening because of the synthesis microbial cell synthesis process it requires the ammonia which obtained from the reduced reduction of nitrate to ammonia and it is then it is in progress. So, if ammonia nitrogen is not available in the wastewater it use the nitrate present in the systems and it reduce it and then it use the it use it for the microbial cell synthesis this is called the assimilation reduction of nitrate. While in the dissemination reduction the nitrate is used as a terminal electron acceptor for anoxic oxidation of other anoxic oxidation of process oxidation process when other electron donors like oxygen is not available in the wastewater.

So, that means, in case of anoxic oxidation it means when the oxygen concentration is almost 0 in the system. So, because of the limitation of the oxygen which can act as a electron donor nitrate starts acting as a electron donor and because of that the dissemination process reduction process occurs and in that case the we can get rid of the nitrate from the system. In general the denitrify microorganisms which it either uses use either the dissolved oxygen or nitrate as a oxygen source for the cell metabolism process. For effective denitrification to occur the dissolved oxygen level should be close to 0 preferably less than 0.

2 milligram per liter or 0.2 ppm parts per milliamp right. So, in general there is a wide range of microorganisms both heterotropic as well as autotropic they have the ability to demonstrate the denitrification of wastewater via reduction of nitrate into nitrogen gas. One of the famous most commonly like you know we know about it is a pseudomonas species which are most commonly detected in the wastewater. So, how this process occurs you see this nitrate NO 3 it converts into nitrate nitrate to nitric oxide nitric oxide to nitrous oxide nitrous oxide to nitrogen gas. So, this is the sequence of the event that happens when the steps that it happens in this 4 steps we finally, get the dinitrogen gas or the nitrogen gas.

So, this nitrogen gas it what happens then it evaporates it gets rid of the system I mean like it like eliminated from the systems because of its because it is in its gaseous form and that is it you can you can get rid of the nitrogen in general from the system itself from your wastewater itself. So, that is how you get rid of the nitrogen from your wastewater and it converts into the gaseous nitrogen. So, this is the process of denitrification this is how it works. So, what are the different other microorganisms which undertake this denitrification reaction the bacillus, pseudomonas, rhodoceromonas, the bivirio, chromobacterium, spirulum etcetera. So, in case of biological denitrification process sufficient amount of carbon source must be available for the growth of heterotrophic denitrification microorganisms.

Please remember there is one lacuna one problem is there with the denitrification process that these are majorly the heterotrophic microbes and this heterotrophic microbes they also need the carbon source. So, only nitrate is not enough. So, also they need the carbon source. So, if the carbon source is not available in your system you have to somehow supply it.

We will discuss about it in details how it works. So, in general theoretically 4.2 gram of COD is required per gram of nitrogen for total nitrogen removal of with glucose as a carbon source. In general with different wastewater constituents not only glucose is like in the pure form of carbon. So, in case of carbon based diet in case of other you know cases like when a wastewater which is a mix a complex mix of different type of nutrients in that case the ratio can be somewhere between 4 to 15 gram of COD per gram of nitrogen present in the system. So, that is how it shows the I mean like your nitrogen denitrification will only occur if you have this much of COD available in your system.

In order to meet this requirement sometimes we add the external externally we add externally the methanol as a carbon source and sometimes the some fraction of the untreated seawater untreated wastewater can be also added or admitted to the denitrification reactor. So, why untreated wastewater because untreated wastewater still have a high proportion of carbon base source carbon material right the so, I mean like in the form of COD we can we can easily justify we can easily actually like you know showcase. So, in this case there are two options first you externally supply some methanol or some other sources some other carbon source and second is to just simply supply the untreated wastewater in the denitrification process itself ok. So, in general when we use the external source like methanol and we call it external source like you can see this reaction in the equation number 9 where the methanol is used for when it actually utilized for the process of denitrification it converts the nitrate into nitrogen plus carbon dioxide H2 and some amount of OH compound OH radical will also be generated OH negative either radicals or also in the form of like ion it can also generate. So, likewise when the if the carbon source in the system is there from the system itself you are using like you know bacterial sludge or influent wastewater it is called the internal carbon sources ok.

In general when there is like you know there is no carbon source and all you are using some the microbes itself which will go through its the process of like endogenous decay kind of stuff. So, there this microbes itself they consume the nitrogen converted into nitrogen carbon dioxide H2O, NO3, NH3 and 10 number of OH negative. So, in denitrification process this is how it works. So, if you remember that in the nitrification process when we were discussing about it reduces it eliminated it eliminates the alkalinity. However, in case of denitrification process it produces some amount of alkalinity in the into the system.

So, in general 3.57 gram of alkalinity in terms as calcium carbonate per gram of nitrate is produced in the system ok. So, in case of nitrification process it was almost 7.5 whereas, in case of denitrification process this is around 3.57 gram of alkalinity that it produces rather produces ok. So, what are the factors that it affects on this denitrification process? Obviously, the dissolved oxygen concentration it should be as little as less than 0.

2 milligram per liter because if somehow it increases the if you somehow you increase the presence of oxygen if there is a increase in presence of oxygen what will happen? Instead of nitrate being the electron donor this acceptor the oxygen will become the terminal electron acceptor in the system isn't it. So, if oxygen will accept the electron

that means, it will get reduced and the system will like instead of nitrate the oxygen will get reduced ok. So, this is this is why it is the system in general we prefer not to have a in the denitrification process we try to maintain anoxic condition in the system ok. Availability of the carbon source which is very vital very vital believe me there are multiple cases where we normally deal in the regular basis in industries and all where the people they ask like why our denitrification system is not working we have done everything right and all. But later we found that you know the waste water that it enters into the system does have a very little amount of carbon left for the heterotrophic denitrification denitrifying microorganisms to actually survive in the system.

So, the COD value is very important you have to maintain a at least 4 to 15 milligram of COD per to TKN ratio that is very important I mean 15 to 4 to 15 ratio of this COD to TKN you have to maintain for denitrification process. Sometimes methanol is suitable, but it is a costly process right. So, that is why ideal source of carbon is like the waste water itself you supply the raw waste water itself time to time there will be like a if you have a certain stages and then you have the denitrification you somehow bypass some of them and add the waste water in the denitrification process some little bit in amount. Total quantity of methanol that can that is required you can easily estimate you can using this equation 11 in absence of the precise data like methanol dose like 2.

47 times of the nitrogen nitrate removed, 1.53 times the nitrate removed and 0.87 times the DO removed from the system ok. Because it is not only the some of the methanol is utilized by the microbes to actually it utilized by for the DO removal of the dissolved oxygen from the system as well. So, whatever the presence of DO is there some amount of methanol will be utilized by some microbes which will consume the further whatever the rest amount of DO that is there it consumes it and it actually utilize it for its respiration process. So, in general with this equation this is a thumb rule you can easily get an idea about the tentative doses of methanol in your reactor ok.

The pH is another important factor it has to be it has to be high it has to be 6.5 to 8 is quite appropriate whereas, in case of it is lower than 6.5 the rate of denitrification will start reducing and it not only start reducing it reduces drastically from the system ok. So, in general the nitrification process it involves we understood that it is a two step process first ammonia it converts into nitrate then nitrate it converts into nitrate. So, primarily it is carried out by the autotropic microbes like the nitrosomonas and the nitro factor.

It is very important to maintain a specific conditions like the pH dissolved oxygen and the carbon sources for to ensuring the effective nitrification process to occur. If there is a need of denitrification if your regulatory body says that further removal of total nitrogen is required. So, you go for denitrification. A denitrification process in general in what we do we convert the nitrate into nitrogen gas using the my different type of microbes those are those are the majorly depending on the factors like the dissolved oxygen concentration availability of the carbon sources and the pH level. And one of the best suggestion that one of the best suggestion that we can give it to you give to you that about the denitrification process always use the waste water itself for the suitable source of carbon for having the proper carbon COD to TKN ratio.

You remember TKN right total gel-dell nitrogen right the total this nitrogen ratio you have to maintain. So, these are this is this is it. So, in these are the references that you can follow and where you will get some more in-depth idea about this discussions that we had just now in this lecture. So, I would suggest you to go ahead with further literatures and to get an get a more idea get some more in-depth idea or the knowledge about the system overall the system itself. Furthermore, I would also suggest I mean like anyway in the coming lecture we will be discussing about the different design different type of reactors that normally we use which is which actually combinedly use the nitrification and denitrification fundamentals together ok.

So, we will discuss about in the coming lecture and we will also discuss about the anammox process which is very advanced process of nitrogen removal from the system from the wastewater and I hope you will like it. So, let us catch up in the next video. Thank you so much.