Water and Wastewater Engineering
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Aeration Nitrification and Denitrification
Lecture – 24

Last class we were discussing about the activated sludge process in detail. we have seen the important design parameters, we have seen how to calculate total sludge production, what is the loading rate we can adopt and we have seen what is the oxygen requirements what is the nutrient requirement and we also discussed how to design the secondary sedimentation tank of an activated sludge process.

We were discussing about the aerators because we have to supply excess oxygen externally by means of mechanical means because the oxygen consumption rate in an activated sludge process is much more compared to the rate at which oxygen is entering in the system naturally. So, if you want to meet the oxygen requirements extracted by the microorganisms in the aeration tank we have to supply that much of oxygen so that is why we have to provide aerators. The aeration facilities are having two major objectives; one is to provide enough oxygen whatever is required for the activated sludge process for the proper performance of the system and the second one is to provide proper mixing in the system.

If proper mixing is not taking place in the system then all the microorganisms whatever is present in the system will be settling down and the substrate wastewater will be in the top so there will not be any contact between the microbial cells and the organic matter present in the wastewater.

Unless the organic matter goes and gets attached to the microbial cells there will not be any metabolism taking place. If there is no metabolic activity taking place definitely there will not be any treatment or any change in the status of the organic matter. What I mean is, it will not be getting converted from the dissolved form to the colloidal form or new cells so proper mixing is also very much essential in an activated sludge process.

When we talk about the mixing everything depends upon the reactor region we are adopting. If it is a completely stirred tank reactor we have to have proper mixing. If it is a plug flow reactor there will not be any longitudinal mixing but transverse mixing will be taking place because each portion of a plug flow reactor will be acting as a completely mixed batch reactor.

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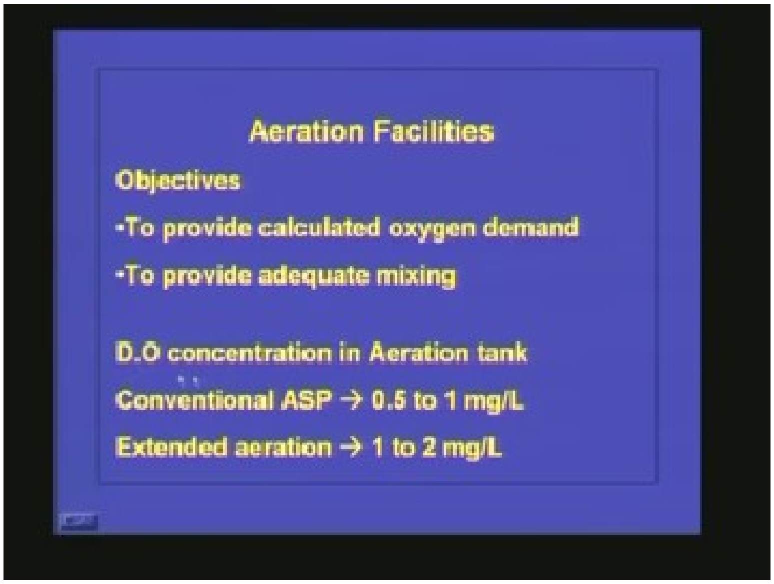

So if you talk about the aeration requirement in aeration tank it varies depending upon the process. the dissolved oxygen concentration in the aeration tank of a conventional ASP varies from 0.5 to 1 milligram per liter whereas in extend aeration it varies from 1 to 2 milligram per liter so your aerators should be able to provide this much of dissolved oxygen in the system irrespective of the oxygen demand exerted by the system.

We will know what the total oxygen requirement is. We have already seen how to calculate the total oxygen requirement of a particular biological system. Now we have to find out how many aerators we have to provide and what type of aerators we have to provide. We also discussed that the aerators can be classified into two categories; diffuse aerators and mechanical aerators.

Diffused aerators are mainly used in plug flow type of reactors and mechanical aerators are commonly used in CSTR type reactors but they are interchangeably used in exceptional cases. If you want to find out what is the number of aerators we have to provide in the aeration tank to give the sufficient amount of oxygen we should know what is the capacity or what is the amount of oxygen that can be transferred by a single aerator. We also discussed about the factors that affect the oxygen transfer.

The factors that affect oxygen transfer are the oxygen saturation concentration or the oxygen concentration gradient available in the system. The next one is the temperature and third one is the wastewater characteristic and fourth one is the degree of turbulence. If the concentration gradient available is high definitely there will be a high driving force from the high concentration range to low concentration range. At a faster rate the oxygen will be getting transferred so the saturation concentration or the dissolved oxygen concentration of the wastewater is very very important. That will decide the rate of oxygen transfer. Another one is the temperature. As we know at low temperature the dissolved concentration is very high and as the temperature increases the dissolved oxygen concentration will be coming down. The next one is the wastewater characteristic. Because if the water is having this much of dissolved solids naturally the dissolution of oxygen will be getting affected because of that. The other parameter is the presence of hydrophobic substances.

Hydrophobic substances are those which is disliking water. That means they will be having tendency always to come out of water. So what will happen is whenever this hydrophilic hydrophobic compounds are there the hydrophilic compound will also try to be in the water and hydrophobic particles or hydrophobic compounds will be forming a thin layer over the surface of the water because at any chance given to them they will want to come out of water (hydrophobic) because they dislike water. Therefore when these hydrophobic substances form a concentrated layer of molecules on the surface of the water naturally some other molecule is coming from outside and if it tries to enter into the water then definitely it will be entered by this layer. So the wastewater characteristics are also very very important when we discuss about the oxygen transfer capacity.

Another one is turbulence. If the water is quiescent naturally the oxygen transfer will be less but if the water is highly turbulent because of the turbulence more mixing will be taking place so naturally the oxygen transfer will be higher. When we talk about the aerators about which condition we have to talk. Since different treatment plants we take the conditions prevailing there will be entirely different thus the wastewater characteristic can be changed, the turbulence whatever is there in the system can be different, the temperature can be different and the dissolved oxygen concentration difference might be there because whatever saturation concentration is already present in the system can vary from system to system. So how can we compare the performance of aerators?
That is why we use the term rating of aerators.

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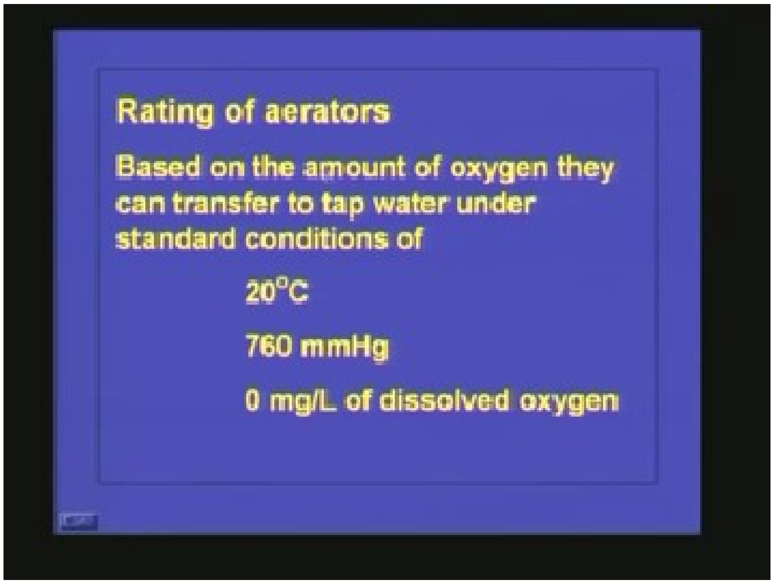

Rating of aerators is based on the amount of oxygen they can transfer to tap water under standard condition of twenty degree centigrade, 76 millimeters of mercury and 0 milligram per liter of dissolved oxygen. These conditions are very very important because we are going to compare the efficiency of each aerator. So, at that time what we have to do is we have to maintain the standard condition and that standard condition is 20 grade centigrade 76 millimeter of mercury and 0 milligram per liter of dissolved oxygen. So if you want of find out the rating of aerators under standard condition how can we conduct the experiment?

It is very easy. You have your design aerator and you have a proper tank which is having proper dimensions. Usually the dimension of the tank is maintained in such a way that d by 2 that means width by depth ratio will not be greater than 2. From the experience it is shown that if the ratio is less than 2 then the oxygen transfer efficiencies higher compared to a higher ratio. So usually they make the standard tank then what they do is fill the tank with tap water and definitely the tap water will be having some dissolved oxygen present in that one. So we have to make the dissolved oxygen concentration to zero that is the standard condition. So how can we make the dissolved oxygen concentration to zero is we have to add some reducing agents.

Reducing agents are the ones which accept oxygen and get oxidized and oxygen will be getting reduced to water so usually we add sodium sulphide Na_2 So_3 so what will happen is this sodium sulphide will be combining with oxygen present in the tank and it will be forming sodium sulphide Na_2 So_4 and all the oxygen whatever is presented in the system will be coming down to zero then you start your aerator keeping 76 mm mercury pressure and temperature as 20 degree centigrade and measure what is the dissolved oxygen concentration at a given time. From that one we can find out what is the rating of aerators. But this rating if you think that the same efficiency will be prevailing in field condition it is wrong because in field condition the situation is entirely different the temperature may not be 20 degree centigrade and pressure may be same or may not be same but dissolved oxygen concentration will be different. Most of the time it will be in the range of 1 and not 2 milligram per liter so we have to convert this rating of aerator to filed condition. For that one we use another term that is known as oxygen transfer capacity.

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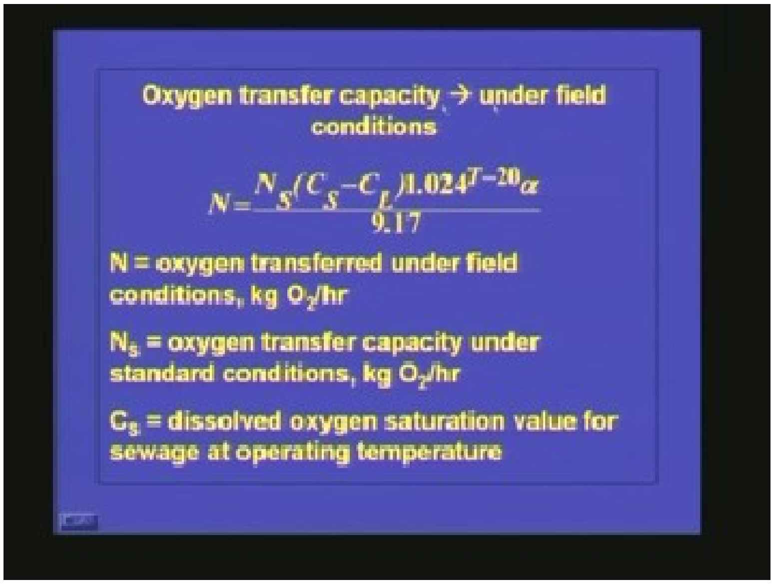

This oxygen transfer capacity we define under field condition whatever exists in the field so depending upon the wastewater characteristics, depending upon the turbulence, depending upon the temperature and the dissolved oxygen concentration we can find out what is the oxygen transfer capacity. This is the commonly used formula to calculate the oxygen transfer capacity N is equal to n N_S into C_S minus C_L into 1.024 raised to T minus 20 into alpha divided by 9.17.

Here this N is oxygen transferred under field conditions, kilogram oxygen per hour this is the field condition and N_S is oxygen nothing but the oxygen transfer capacity under standard condition. This N_S value will be available along with the aerator because this will be found out by the manufacture under standard conditions. This will be given to you so this value you will know and C_S is the dissolved oxygen saturation value for sewage at operating temperature. So this one we can get from standard tables, what is the saturation concentration. It is the function of temperature and pressure. So if you know the temperature at that time we can find out what is the maximum dissolved oxygen concentration we can get. And CL is the operating dissolved oxygen level in the aeration tank. Usually it will be 1 to 2 milligram per liter and T is the temperature in degree centigrade because this is the operating temperature.

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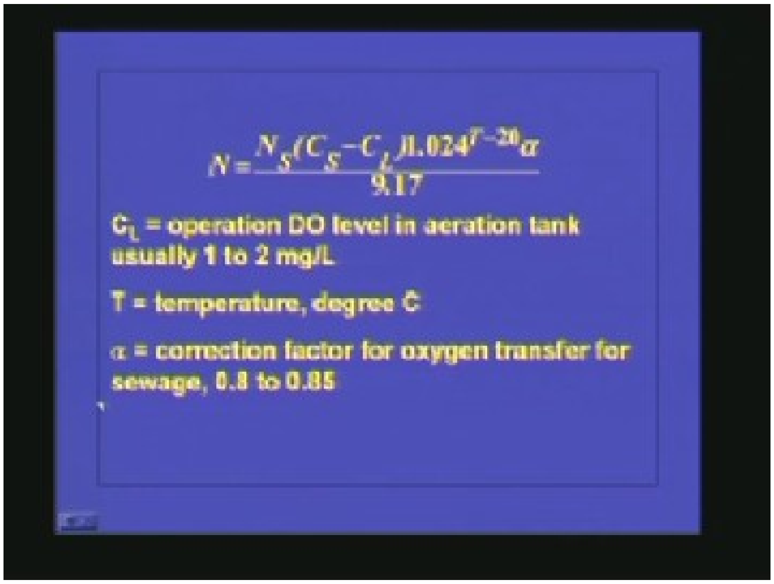

We know that the oxygen transfer capacity reduces with increase in temperature so we have to make the correction for the temperature also and alpha is the correction factor for oxygen transfer for sewage because under standard condition we are finding out the transfer for tap water. There not many solids are present or the dissolved solid concentration is very very less and organic matter concentration is almost negligible. But when we talk about the wastewater the condition or the situation is entirely different so we have to make a correction and that correction factor is this alpha (Refer Slide Time: 13:23) so that varies from 0.8 to 0.85.

So if you apply these corrections then based up on the rating of the aerator we can find out what is the aerator field capacity, what is the amount of oxygen that can transfer under filed condition. We have already found out what is the oxygen required by the system. So we know what is field capacity of the aerator and we know what is the total amount of oxygen required by the system. Hence we can find out what is the number of aerators we have to provide or what is the … (noise 1400) we have to provide.

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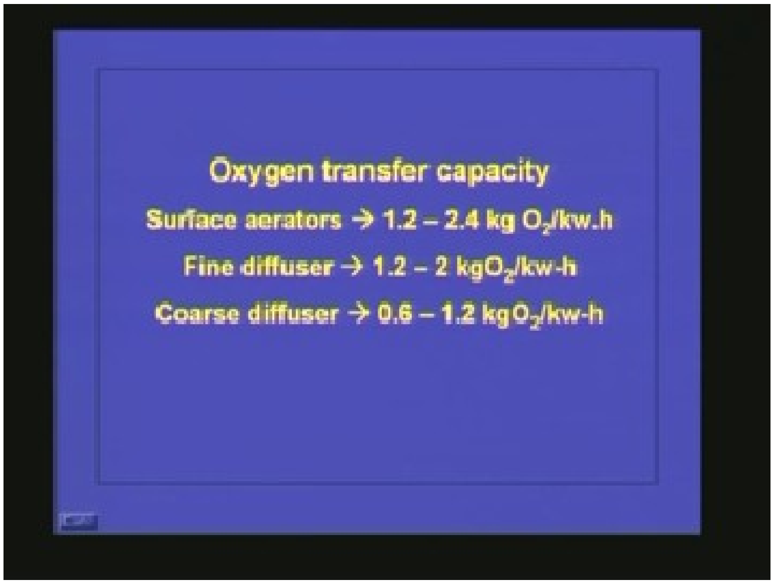

Here I have given the oxygen transfer capacities of varies type of aerators. If we go for surface aerators in most of the cases in India we use surface aerators. There oxygen transfer capacity varies from 1.2 to 2.4 kilogram of oxygen per kilowatt hour. And if you go for fine diffusers the oxygen transfer capacity is 1.2 to 2 kilogram oxygen per kilowatt hour and if you for coarse diffuser the oxygen transfer capacity is 0.6 to 1.2 kilogram oxygen per kilowatt hour.

The fine diffuser is having high oxygen transfer capacity. The reason is the bubbles whatever is coming out of the diffuser will be very very fine so the contact area of the bubbles with the liquid is very high. Therefore when the contact area is more the transfer oxygen will be very high. But the disadvantage of this fine diffuser is that the clogging chances are very high because the passers are fine it can get clogged very fast. The other problem with fine diffusers are the pressure drop experience in these diffusers are very very high so we have to apply a very high pressure of inlet air then only it can give sufficient aeration.

When we talk about the coarse aerators the pressure drop will be very very less and the bubbles whatever is coming out will be bigger ones so naturally the oxygen transfer capacity will be less. So, in order to increase the oxygen transfer capacity using the coarse diffusers what usually is practiced is to use a turbine just above the coarse diffuser so the bigger bubbles will be coming out of the coarse diffuser and this turbine will be breaking the bubbles into finer ones and it increases the oxygen transfer capacity. Moreover the turbine will be increasing or inducing more turbulence that will be increasing the oxygen transfer rate.

For surface aerators the most commonly used one here for oxygen transfer capacity is relatively higher compared to fine diffusers and coarse diffusers.

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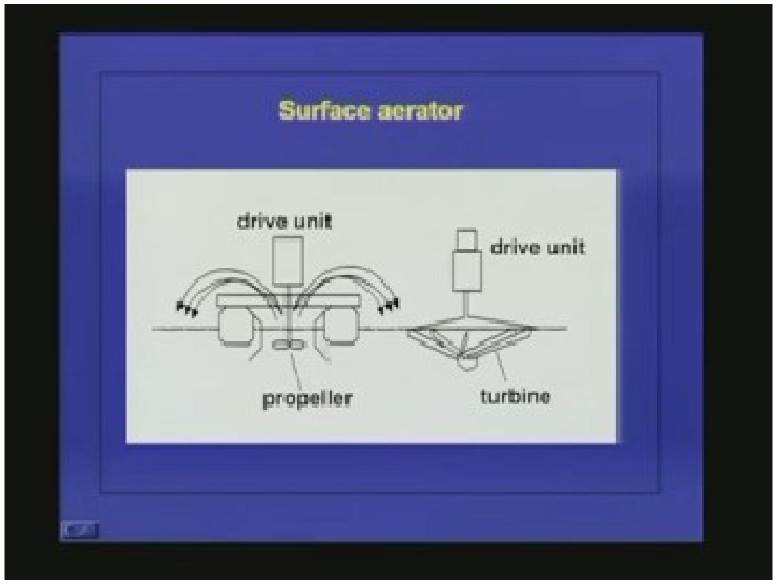

This is a picture of a surface aerator. We can see that the surface aerator is here and so much of turbulence is there, so much of mixing is there and it is transferring the air to the water.

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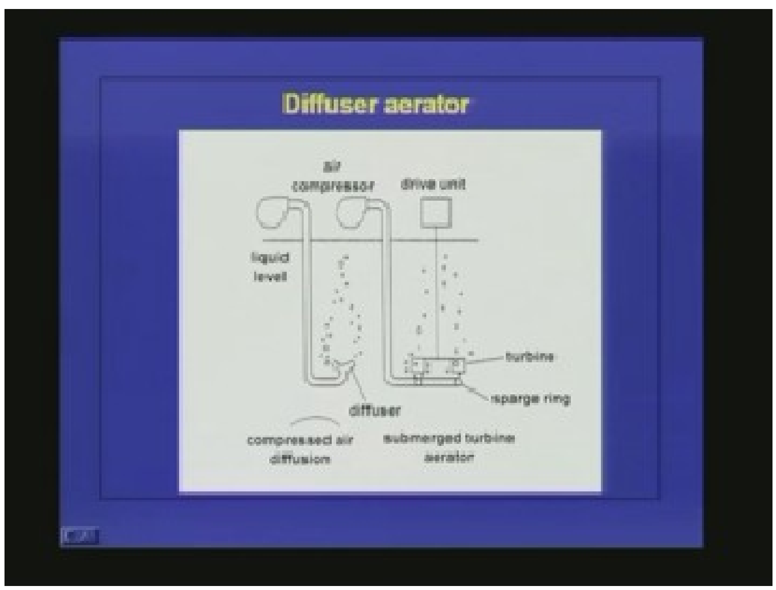

This is an example of diffused aerator. This is the oxygen supplying pipe (Refer Slide Time: 16:39) and diffusers are placed at the bottom, we can see this here and fine bubbles will be coming out of the diffusers and it will be aerating the entire system. And once again the diffused aerators are mainly used for plug flow type of reactors or surface aerators are used for CSTR type reactors.

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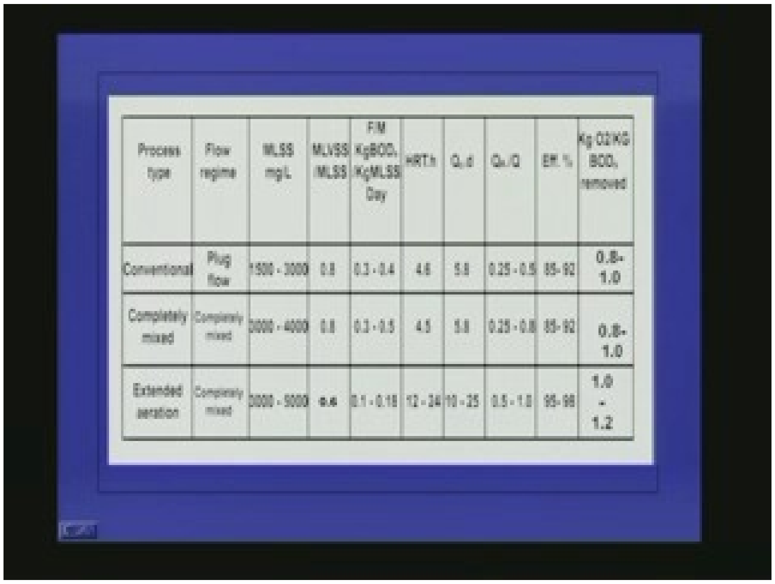

Process type	Flow regime	MLSS mg/L	MLVSS /MLSS	F/M KgBOD, /KgMLSS Day	HRT,h	Q_c,d	Q_r/Q	Eff. %	Kg O2/KG BOD, removed
Conventional	Plug flow	1500 - 3000	0.8	0.3 - 0.4	4-6	5-8	0.25 - 0.5	85-92	0.8-1.0
Completely mixed	Completely mixed	3000 - 4000	0.8	0.3 - 0.5	4-5	5-8	0.25 - 0.8	85-92	0.8-1.0
Extended aeration	Completely mixed	3000 - 5000	0.6	0.1 - 0.18	12 - 24	10 - 25	0.5 - 1.0	95-98	1.0 - 1.2

Now I will give some information which is essential for the design of activated sludge process. We have discussed in detail about activated sludge process; what is an activated sludge process, how to design activated sludge process under various conditions, you will be getting different parameters so how can we go around with the design and we have also seen about what are the important design parameters. We also discussed about what is the purpose of an aerator and how to design an aerator or how to find out how many number of aerators we have to provide in the system. This gives the summary of entire discussion.

Here the process, flow regime and details of what concentration is required etc is given. I will just read out.

If we are going for conventional type activated sludge process, if the flow regime is plug flow the MLSS concentration varies from 1500 to 3000 milligram per liter and the ratio of MLVSS by MLSS that is 0.8 and f is to m ratio that means nothing but food is to microorganism ratio or the specific substrate utilization rate varies from 0.3 to 0.4 and hydraulic retention time in the aeration tank varies from 4 to 6 hours and biological sludge process retention time theta c varies from 5 to 8 days.

Here we can see the difference. Here HRT is varying from four to six hours and theta c is varying from 5 to 8 days and the recirculation ratio is point two five to point five and the efficiency varies from 85 to 92%. Kilogram of oxygen required is kilogram of BOD removed. Usually we have to provide point eight to one kilogram of oxygen. So from this one we can find out what is the horse power required. And if you go for conventional activated sludge process with a CSTR flow regime that means completely mixed flow regime the MLSS concentration usually is in the range of 3000 to 4000 milligram per liter and here also (Refer Slide Time: 19:24) MLVSS to MLSS ratio is 0.8 and food is to microorganism ratio we can change from 0.3 to 0.5 depending up on the type of system we are adopting and HRT varies from four to five and theta c varies from 5 to 8 days and QR can vary from 0.25 to 0.8 again depending up on the process and efficiency is 85 to 92 and oxygen transfer rate is exactly the same 0.8 to 1.

Now we will come to the extended aeration system. The advantage of this system we have already discussed. There is no sludge handling problem because entire sludge is getting stabilized or the sludge or the microorganisms are undergoing auto oxidation. So whatever sludge is coming out of the extended aeration system is mainly inorganic substances. So we can directly take the sludge and dispose it into sludge drying buds. So naturally if we want to completely oxidized the entire organic matter then the oxygen requirement will be more. So we will see what are the requirements for extended aeration system.

If we go for completely mixed flow regime the MLSS concentration varies from 3000 to 5000 and MLVSS by MLSS ratio is 0.6. The reason is most of the microorganisms are in the endogenous respiration state so much amount of inorganic substances will be there in the system that is why this MLVSS by MLSS ratio is coming down.

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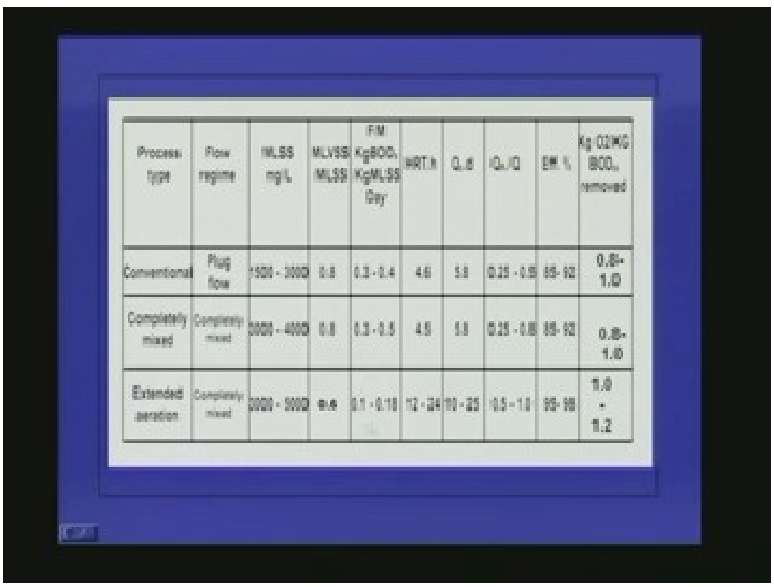

Process type	Flow regime	MLSS mg/L	MLVSS/MLSS	F/M KgBOD5/KgMLSS/Day	HRT,h	θc,d	Qr/Q	Eff %	Kg O2/KG BOD5 removed
Conventional	Plug flow	1500 - 3000	0.8	0.3 - 0.4	4-6	5-8	0.25 - 0.5	85-92	0.8-1.0
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Extended aeration	Completely mixed	3000 - 5000	0.6	0.1 - 0.18	12 - 24	10 - 25	0.5 - 1.0	95-98	1.0 - 1.2

Now we will discuss about the food is to microorganism ratio. In extended aeration system we keep the food is to microorganism ratio very low. The value varies in between 0.1 to 0.18 and mostly the microorganisms are kept under starvation.

Now we talk about the hydraulic retention time. It varies from 12 to 24 hours because the entire microorganisms have to get oxidized and that is why it takes such a long hydraulic retention time. And theta c here is 10 to 25 days. If you see the theoretical theta c value in an extended aeration system it will come to almost infinity and the recirculation ratio is 0.5 to 1.

In most of the cases what we do is the entire sludge whatever is generated in the extended aeration system will be re-circulated. But practically to avoid the accumulation of inorganic solids in the system around 5% of the sludge will be wasted so that is why the recirculation ratio is coming as high as to hundred percentage recirculation. And if we talk about the efficiency of extended aeration system the efficiency varies from 95 to 98% because we are giving so much of aeration so the entire organic matter will be getting oxidized. This is the summary of activated sludge process.

While talking about the oxygen requirement definitely extended aeration system will need more oxygen around 1 to 1.2 kilogram of oxygen per kilogram of BOD removed is required because everything is getting oxidized so there is no need of any further sludge treatment.

Till now we were discussing about how the organic matter is getting removed from the system. But we all know that apart from the organic matter there are nitrogenous material present in the wastewater. The nitrogen can be in the form of organic nitrogen or ammonia nitrogen. From where, this nitrogen is coming to the wastewater? We know that the basic component of any protein is amino acids and we will be taking lot of proteins as a part of our food and decaying of any vegetables or any protein containing substances will be releasing this organic nitrogen and ammonia nitrogen. So, when we provide aeration what will happen is first the microorganisms will be utilizing all the carbonaceous material present in the system then it will start utilizing or start oxidizing the ammonia to the most oxidized form that is nitrate. So, for this also we have to provide some oxygen.

When we were discussing about the total oxygen requirement of the system we have seen what is the nitrogenous oxygen demand. If you have one unit of ammonia nitrogen present in the system we need around 4.57 units of oxygen. That means one unit of ammonia requires 4.57 units of oxygen. So who is doing the oxidation of ammonia to nitrate? Is it the heterotrophic microorganism whatever is presented in the system or is it some other microorganism. What all are the conditions which are required for the proper oxidation of this ammonia to nitrate. If complete oxidation of ammonia to nitrate is not taking place in the treatment plant then if you discharge the effluent whatever is coming from the treatment plant to the water bodies it will be exerting some oxygen demand which is not advisable so complete oxidation of this nitrogenous material is also essential in the treatment plant.

When we were discussing about the population or the nature of microorganisms in the activated sludge process we have seen that there are various types of bacteria, fungus, protosova etc are present in the activated sludge process and in bacteria we have seen there are heterotrophic bacteria and autotrophic bacteria. So this ammonia oxidation or organic nitrogen oxidation to ammonia then nitrite to nitrate is taking place with the help of autotrophic microorganism known as nitrifiers.

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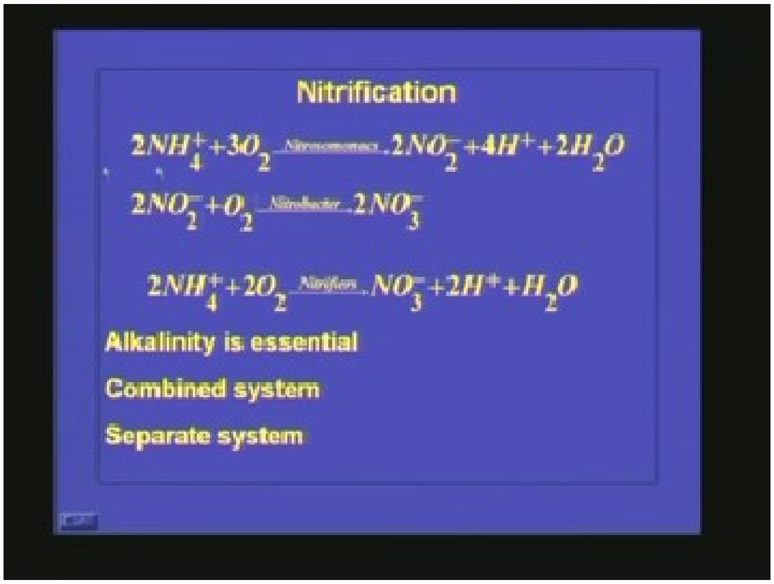

Nitrifiers are responsible for the oxidation of ammonia nitrogen to nitrate. This is very very clear when we discussed about the biochemical oxygen demand. If you see the biochemical oxygen demand curve with respect to time we have seen that up to fifth day or seventh day initially it is following the first order then it attains the zero order reaction and it becomes asymptotic and after certain time again there is rise and again it will become to zero order. So the second rise is because of these nitrifying bacteria.

Thus, in the initial stage whatever carbonaceous oxygen demand is present will be removed then nitrogenous oxygen demand will be exerted. This nitrogenous oxygen demand or these nitrifiers which exerts this nitrogenous oxygen demand……, (Refer Slide Time: 26:25) these are autotrophic microorganisms. So, if the organic matter concentration in the system is very very high naturally the heterotrophic microorganisms will be driving or their population will be very high. As the organic matter concentration comes down the heterotrophic microorganisms concentration also will be coming down at that time these nitrifiers will start their work.

How they work?

These nitrifiers include two sets of microorganisms; one is nitrosomonas and another one is nitrobacter. Nitrosomonas converts ammonia in presence of oxygen to nitrite plus 4H plus $2H_2O$. And nitrobacter are taking this nitrite and in presence of oxygen they converting it into nitrate. So we can see that the ammonia oxidation will be releasing hydrogen ions so definitely the pH of the system will be coming down so we have to provide alkalinity to the system.

Moreover we have seen that these nitrifiers are autotrophic microorganisms. From where does the autotrophic microorganisms are getting the carbon for cell synthesis? It has to come from inorganic sources. So usually the nitrifiers take the carbon from the bicarbonate present in the system or the alkalinity present in the system. Therefore, if you want to have a proper nitrification in your system the system should have proper alkalinity. If sufficient alkalinity is not present we have to supply alkalinity externally.

Now we will discuss the important things that are essential for proper nitrification. One is alkalinity, second one is oxygen. We can see that for ammonia to nitrite we need three molecules of oxygen and nitrite to nitrate we need one molecule of oxygen so enough oxygen supply is essential. But whether the oxygen can be limiting factor for nitrification in the conventional activated sludge process is what we need to know. Sometimes it can be and sometimes it cannot be because the nitrification can be done in a combined system or in a separate system.

Combined system means both the carbonaceous oxygen demand and nitrogenous oxygen demand will be taken care in a single system that is the combine system. And separate system means the carbonaceous oxygen demand removal will be taking place in one system and the nitrification will be taking place in a separate tank.

Therefore, in combined system what will happen is the population heterotrophic microorganism will be very high and we have seen that the microorganism will be forming flocks and the nitrifiers population will be comparatively lower and the nitrifiers usually try to stay on the inner portion of the flock and heterotrophic microorganisms which is utilizing the organic carbon present in the wastewater will be on the outside of flock. So what will happen is whatever oxygen is present in the system if the oxygen concentration is low so what will happen is the diffusion rate will be low so whatever oxygen is getting diffused to the floc will be consumed by the heterotrophic microorganisms at past and if sufficient oxygen is left over then only it will be penetrating to the core of the flock. If it penetrates to the core of the flock then only it will be available for the nitrifiers.

So if you go for combined system then the dissolved oxygen concentration required for efficient nitrification is very very high. That means unless a residual or a dissolved oxygen concentration of two milligram per liter is not maintained in the system nitrification cannot occur that is in case of combined system. But when we talk about separate system the carbonaceous oxygen requirement is taken care in one tank and the nitrogenous oxygen demand is taken care in another tank so in the second tank only nitrifiers will be present. So even if little oxygen is available it will be sufficient for the nitrification. Thus, depending up on the system the oxygen requirement will be varying.

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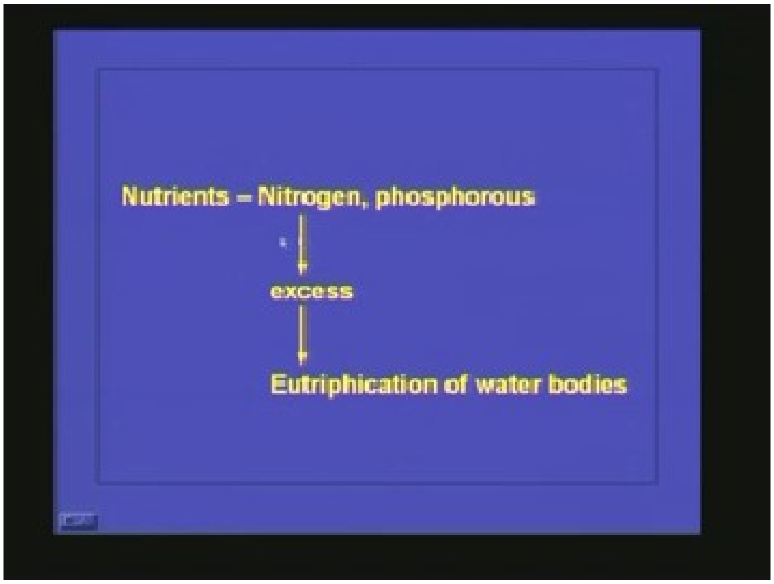

We have seen that the ammonia or the organic nitrogen whatever is present will be getting converted to nitrate with the presence of nitrifiers. That means nitrosomonans converts ammonia to nitrite that means NO_2 minus and nitrobacter converts NO_2 minus to NO_3 minus but is it advisable to discharge the high nitrate containing wastewater or treated water to inlet or the existing water bodies?

It is not because we know that nitrogen and phosphorous are the essential nutrients for plant growth as well as microbial growth. Hence, if the nutrients are presented in excess what will happen is there will be excess alkal growth in the water body or eutrification of water bodies will be taking place so it is not advisable to discharge high nitrate containing wastewater or high nitrate containing treated water to water bodies.

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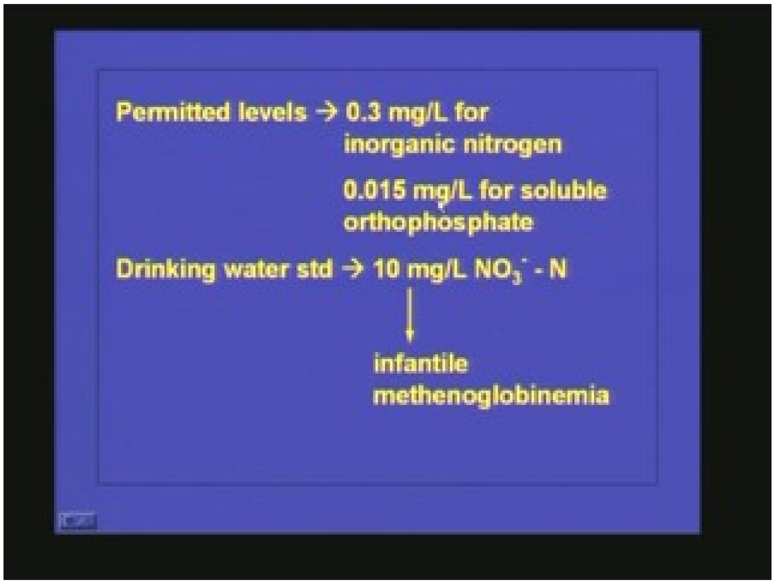

Moreover, we have seen that if high nitrate content is there in drinking water, if the concentration is more than 10 milligram per liter as nitrate nitrogen the methenoglobinemia also will be there so it is not advisable discharge high nitrate containing wastewater. Methenoglobinemia is the disease which is affecting the infantile. We have discussed about this in detail when we were discussing about the water and wastewater characteristic.

The permitted level is point three milligram per liter for inorganic nitrogen and 0.015 milligram per liter for soluble orthophosphate. So this nutrient removal is very very essential. How can we remove this nitrate whatever is presented in the wastewater because the treated wastewater will be containing very high levels of nitrate. Therefore, what are the methods we can adopt for the nitrate removal from the treated wastewater? Those methods are; one is ammonia stripping by aerating. That is, before nitrification itself we can remove the ammonia. So once the ammonia is removed from the system there will not be any nitrate because the initial compound is not present so the oxidized form of that compound will not be generated.

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Next one is selective ion exchange. If you have nitrate present in your system you can use ion exchange less than resins which is having high affinity to nitrate or anions then they can remove the nitrate present in the system. Another one is breakpoint chlorination. This we have seen when we were discussing about chlorination. If ammonia is present then monochloramine, dichloramine, trichloramine etc will be forming and if you again add chlorine then this tricholramine will be breaking up to nitrogen gas and chloride.

The fourth step or the most commonly practiced process especially for wastewater is biological denitrification. Microorganisms themselves can be used for the removal of nitrate from the system that process is known as nitrogen removal or denitrification.

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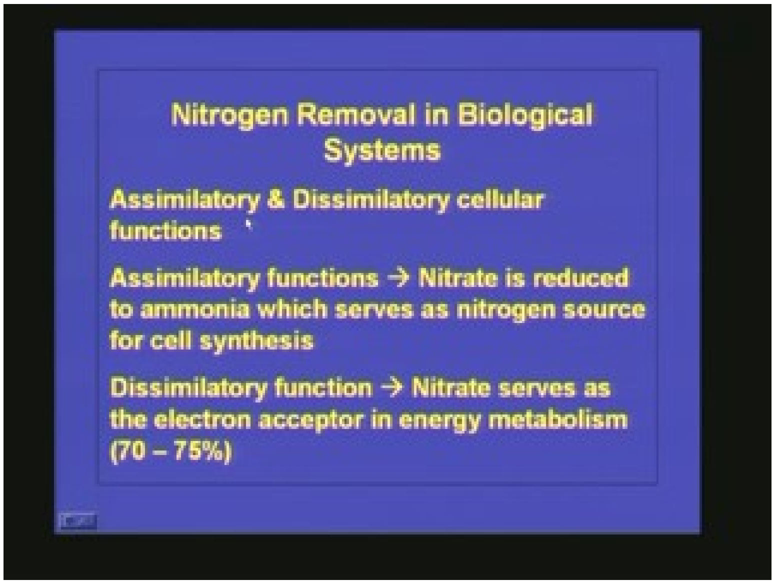

We were discussing about the nitrogen removal or nitrate removal from the system. This nitrate removal can take place in two different ways. One is assimilatory and another one is dissimilatory cellular functions. In assimilatory function is we have discussed that about what is the nutrient requirement for any biological system. The essential nutrient includes nitrogen and phosphorus. We have also seen that for each gram of cell we have to supply 0.122 grams of nitrogen and around 0.023 grams of phosphorus. So naturally, if so much of cell growth is there in the system so whatever the nitrate present in the system will be utilized as a nutrient so that is known as assimilatory.

The amount of nitrogen whatever is utilized for the cell synthesis that is coming under assimilatory category and dissimilatory is the one which is utilized for cell synthesis. It can be used for energy purpose or for just removing from the system. That is what I have written here.

Assimilatory functions: nitrate is reduced ammonia which serves as nitrogen source for cell synthesis and dissimilatory function nitrate serves as the electron acceptor in energy metabolism or dissimilatory function is the one which is utilized for the metabolism of the cell and assimilatory is utilized for the anabolism of the cell. Hence, if you see the total nitrate utilization in the system around seventy to seventy five percentage removal is taking place because of the dissimilatory function and only 20 to 25% is getting removed because of assimilatory function.

Here we can see how the nitrate is getting removed from the system.

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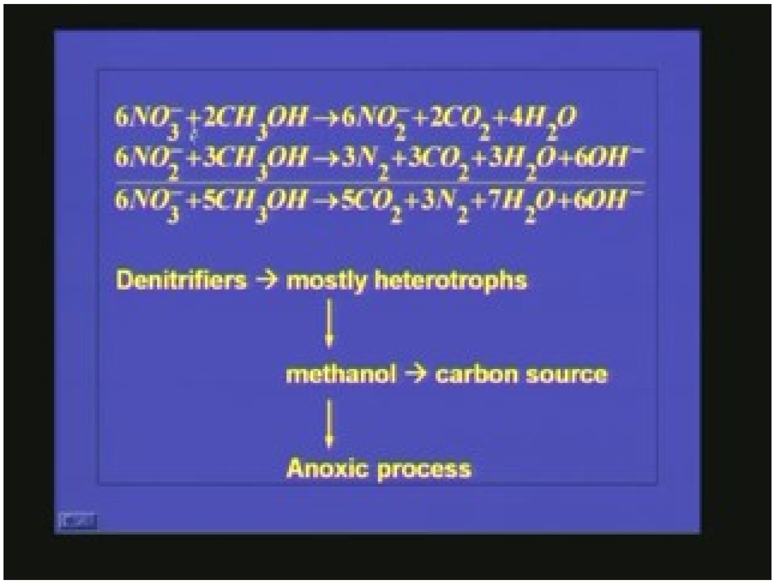

These are the prevailing equations. Nitrate is present. Ammonia is getting oxidized to nitrate by nitrifiers and nitrate is already present there and we have to supply some organic matter. We know that the nitrification will take place after all the organic matter presented in the system is getting removed so there will not be any left over organic matter in the system. But most of these denitrifying bacteria are heterotrophs so definitely they need some organic matter for their cell synthesis. So we have to supply organic matter most of the time in the field. We supply the organic matter in the form of methanol. We can even give the domestic wastewater as such.

The organic matter whatever is presented in the domestic wastewater can be used as food for this heterotrophic denitrifiers. Thus, what happens is the nitrate is getting converted to nitrite then carbon dioxide and water then again this nitrite will be utilized by the denitrifiers and finally we will be getting $3NO_2$ plus carbon dioxide plus water plus 6OH.

We have seen that in nitrification acid is produced. That means for h plus it was coming out and in denitrification we can see that alkanities produced 6OH is coming out or in dinitrification reactors the pH will be coming up whereas in nitrification reactors if proper buffering capacity is not there the pH will be going down. So, if the overall reaction is something like this; 6 nitrate plus 5CH3OH it gives you 5 carbon dioxide $3N_27H_2O$ plus alkalinity.

Denitrification we have already discussed. For any metabolic process the energy is derived from oxidation reduction reaction. For any oxidation reduction reaction there should be an electron acceptor and then electron donor. So here the electron donor is nothing but this methanol. Methanol is acting as an electron donor and we want to reduce this NO_3 to N_2 so this is getting reduced. When one compound is getting reduced it will be definitely accepting electrons.

In denitrification the electron acceptor is nitrate. Denitrification is coming under the anoxic process. We do not have to provide any aeration for denitrification. If aeration is provided then the other heterotrophic microorganisms will be growing faster than these denitrifiers and proper denitrification will not be taking place in the system. Hence, denitrification is an aerobic respiration. That means in the absence of oxygen this denitrification will be taking place. Or precisely we can call it as an anoxic process so inorganic compound containing oxygen will be acting as the electron acceptor. This is about denitrification.

Till now we were discussing about the water and wastewater treatment which is mainly engineered by the people. we know what is happening in the nature and we want to increase the rate at which the reactions can take place so we provide the required environmental conditions in the reactors or the closed chambers so that the microorganisms will be going at a faster rate and they will be utilizing the waste in a faster rate so that we can reduce the volume of the reactor and we can increase the rate or we can increase the treatment efficiency. That is what we were discussing about till now. We have seen activated sludge process, we have seen, what is nitrification, what is denitrification and so on. Now we will discuss about some other suspended growth system where so much of engineering is not required.

We are mostly doing the waste treatment or we are allowing the waste to be treated by the natural forces or whatever is happening in the nature we allow them to take place in a proper manner and the waste treatment will be taking place. That is what happening in ponds and lagoons. What is a wastewater pond? It is a large shallow earthen basin in which wastewater is retained long enough for natural purification process to provide necessary degree of treatment.

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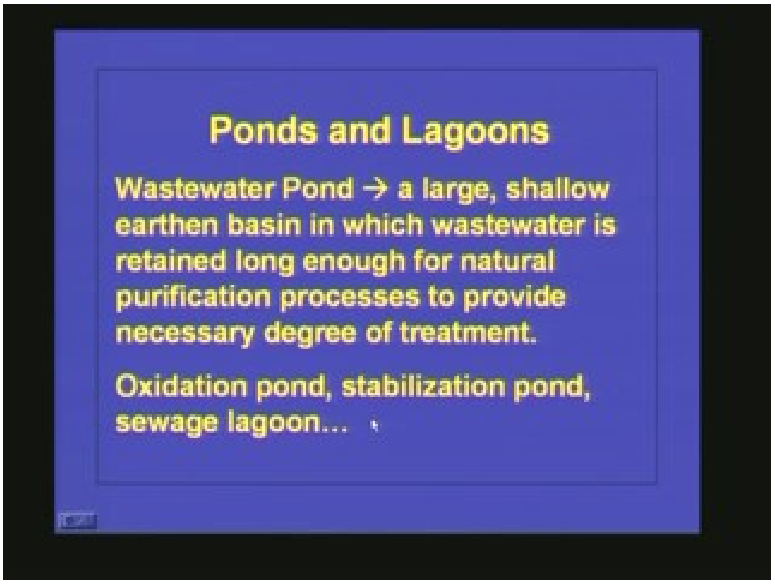

The important thing is, here the retention time is long. We have to retain the wastewater for long time and the process is natural purification. We have to allow enough time for the wastewater so that natural purification will be taking place so that we will be getting the necessary degree of treatment. These ponds are with different names. Sometimes people call them oxidation pond, stabilization pond, sewage lagoon, polishing pond, maturation ponds and so on. We will see one by one in detail.

In ponds and lagoons oxygen supply is mainly by photosynthesis, diffusion of air from the atmosphere. Natural diffusion of air will be taking place and the air will be entering by photosynthesis. First we will see how can we classify the ponds then we will be coming back to the mechanism in detail. What we have to keep in mind is ponds are the system where we retain the wastewater for such a long time that natural purification will be taking place and we will be getting the necessary degree of treatment.

Now we will see what an aerobic pond is. Aerobic pond is a shallow pond; the depth is less than one meter where dissolved oxygen is maintained throughout the entire depth. That means if you see the entire depth of the tank the depth will be varying from 0 to 1 meter the depth will be very very less. So if you see the dissolved oxygen concentration the entire tank or entire pond will be having some dissolved oxygen concentration or at any time the dissolved oxygen concentration will not go to zero so that is the pond which is known as aerobic pond.

In facultative pond what happens is the ponds are 1 to 2.4 meter deep which have an anaerobic lower zone, a facultative middle zone and an aerobic upper zone maintained by photosynthesis and surface aeration. That is the facultative pond.

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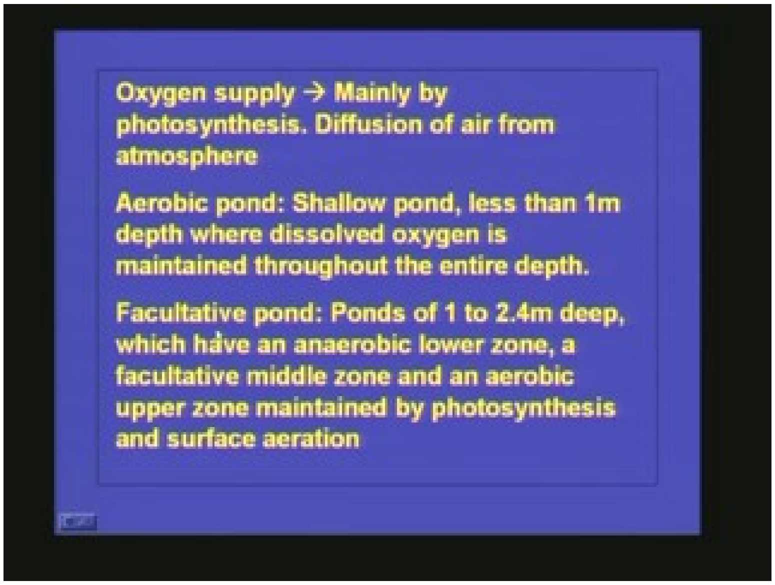

It will be having three distinguished layers; the bottom most portion is anaerobic layer because when the wastewater is coming it will be having so much of suspended solids so definitely it is retained in a closed system so everything will be settling down because the pond will be having a quiescent condition and the depth of the pond is so high as it varies from 1 to 2.25 meters and we do not have any provision for mechanical aeration or artificial aeration. Therefore, aeration will be taking place because of photosynthesis of the algae present in the system and the natural re-aeration.

So the oxygen entering in the system will be very less compared to artificial aeration. So the dissolved oxygen concentration in the bottom of the tank will be zero so there the anaerobic condition will be prevailing and the organic loading or organic concentration is very very high that is why we call it the anaerobic zone. And above the anaerobic zone you will be having the facultative zone. There the microorganisms which can survive under aerobic condition and anaerobic condition will there. There the dissolved concentration will be varying from almost 0 to 0.05 milligram per liter or something like that.

In the top layer we will be having a complete aerobic zone. This aerobic zone is maintained by the photosynthesis of the algae and by the natural re-aeration process. So, there, all the aerobic bacteria will be present. So these bacteria are responsible for the organic matter removal in the top layer and in the bottom layer anaerobic degradation will be taking place.

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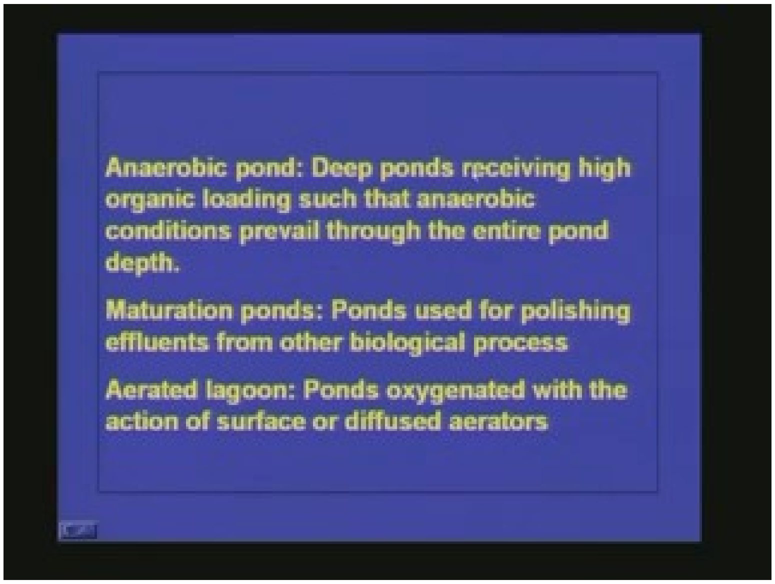

Now, coming to anaerobic pond these are very deep ponds receiving high organic loading such that anaerobic conditions prevail throughout the entire pond depth. In anaerobic pond the organic loading is so high that even the natural re-aeration cannot provide any dissolved oxygen contained in the system because the oxygen demand of the entire system will be so high so the entire tank will be staying in aerobic condition. This type of tanks is used for treating high organic content or high organic BOD or high COD wastewater.

For example if you have the distillery wastewater the COD value varies from 50000 to few lakhs so we can see what is the oxygen requirement for such wastewater. So if you allow them to stay in a tank or in a pond the oxygen requirement will be so high, even though it is exposed to the atmospheric conditions the oxygen transfer will not be sufficient to provide any oxygen to the system. That is what an anaerobic pond is.

Now, coming to maturation ponds, these are the ponds used for polishing effluents from other biological treatment units.

Aerated lagoons are the ponds oxygenated with the action of surface or diffused aerators. Maturation ponds are coming under aerobic ponds most of the time because it will be long, narrow or long wide ponds but the depth of the pond will be very very less. The major function of this pond is to polish the water or the effluent coming from other treatment units. because we have seen that if you go for conventional activated sludge process the removal efficiency varies from 85 to 92% so remaining say fifteen to or seven to fifteen percentage organic matter whatever is present in the system will be coming out along with the effluent.

Moreover, if we talk about the pathogens present in the system that also will be coming with the effluent because in this conventional treatment system either it is aerobic or anaerobic it cannot take care of the pathogens completely or the pathogen removal will not be taking place completely. So, if you want to discharge the effluent from such treatment plants to some existing rivers where people bathe or carry on other recreational activities then this is not meeting the effluent discharge standards in such conditions.

Now, how can we reduce the pathogenic or the microbial counts in such systems?
In such systems we go for the maturation ponds. These ponds will be retaining the effluent whatever is coming from the secondary treatment for a long time and it will be getting exposed to sunlight and we all know that the sunlight will be containing a lot of UV radiation so this UV radiation are responsible for killing the pathogens. Moreover, we are giving such a long time in the maturation pond so whatever untreated organic matter that is coming to the system gets such a long detention time and definitely the microorganisms will be growing in the system so that microorganism will be consuming the organic matter whatever is leftover in the effluent and finally we will be getting clarified effluent. That is why we are calling them as maturation ponds.

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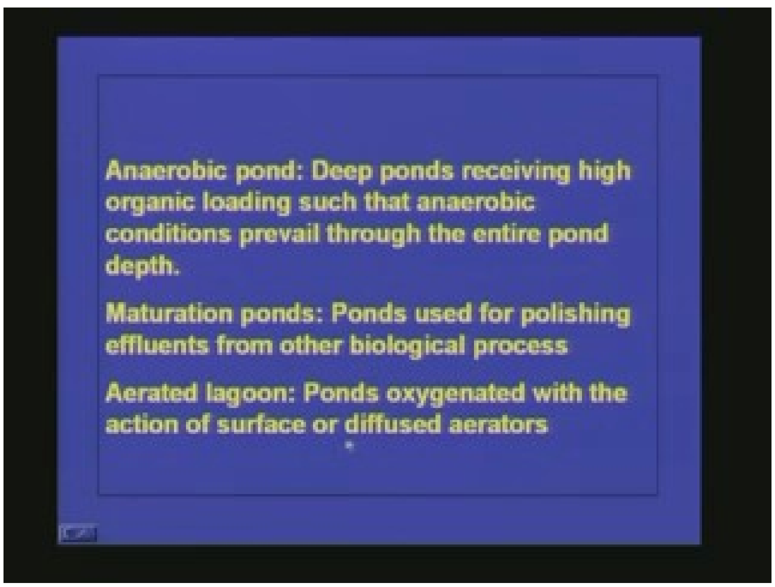

Aerated lagoons are the ones which are the ponds where we give artificial aeration. Whatever natural aeration takes place because of the oxygen diffusion that exists in the system may not be sufficient for proper treatment of the system so in such cases we have to give external aeration. So, for any pond where we provide external aeration is known as aerated lagoons.

Aerated lagoons also can be classified into two categories; aerobic lagoons and facultative lagoons. In aerobic lagoons the complete system is in aerobic condition and entire suspended solids whatever is present in the system will be in suspension. That means the aeration will be so rigorous that all the suspended particles whatever is there or whatever is already settled everything will be coming into suspension and definitely the treatment will be more efficient.

Now we will discuss about the facultative aerator lagoons. In facultative aerator lagoons also we are providing aeration by external means. That means we will be providing aerators. But in this system what happens is the aeration is not as rigorous as that of aerated lagoons or aerobic lagoons so a portion of the suspended particles will be remaining in the bottom or you will be having a facultative zone at the bottom of the tank and the top portion will be completely aerobic. That is the facultative lagoon.

Now we will see the difference between a pond and lagoon. In a pond there is no artificial aeration but for lagoons there is artificial aeration. We have seen the different types of ponds. One is aerobic ponds, another one is facultative ponds and third one is anaerobic ponds and fourth one is maturation ponds.

In aerobic ponds what is happening is the entire depth of the pond is in aerobic condition. The depth will be less and the complete zone will be remaining in a aerobic condition.

In facultative pond the top layer will be in aerobic condition but the bottom layer will be in facultative condition. That means sometimes some dissolved oxygen will be there but sometimes there will not be any dissolved oxygen present. Or in the facultative zone the microorganisms are such that they can survive in aerobic condition as well anaerobic condition.

While coming to anaerobic ponds the entire depth of the pond will be in anaerobic condition. This type of ponds is used to treat high strength wastewater. That means the BOD of the waste will be so high that means whatever oxygen is getting into the system will not be sufficient to maintain any dissolved oxygen in the system.

Maturation ponds are the ones used to increase the quality of the treated effluent whatever is coming from other secondary treatment. That is the purpose of maturation pond. Mostly it is used to achieve bacteriological quality for the discharge.

Now we will see the entire things we have discussed today in detail. We were discussing about aerators and we have seen the major objectives of providing aerator. One is to provide sufficient oxygen to the system and second one is to provide the necessary mixing because mixing is essential for the proper functioning of the system if it is meant to work under completely mixed condition. And even in plug flow reactors though there is no longitudinal mixing transverse mixing is allowed.

We have seen that both diffused aerators and surface aerators can be used. In diffused aerators itself coarse aerators and fine aerators are there. And whenever we want to design the aerators the manufacturer will be giving a rating of the aerator based up on the standard condition. The standard conditions are zero milligrams per liter of oxygen and the pressure is 760 millimeters of mercury and the temperature is 20 degree centigrade and the water used is tap water.

But in actual field condition the systems are entirely different. So naturally the oxygen transfer capacity of that particular aerator will be varying. So rating is just to get a basic idea of that aerator. Hence, based up on that aerator rating we have to find out what is the field condition according to the prevailing condition of the wastewater or prevailing condition existing in the treatment unit.

Therefore, by using proper formula which includes the correction for temperature, the correction for wastewater characteristics and whatever is the oxygen deficit present in the system we can find out what is the field capacity of the aerator. Once we know the field capacity we can easily make out how many aerators or how many horse power we have to supply to the system so that the system will be getting enough oxygen.

We have also discussed about the oxygen requirements for nitrogenous compounds present in the system. We have seen that in activated sludge process we give more importance for the carbonaceous oxygen demand removal. But once the organic matter is removed the nitrogen whatever is present in the organic nitrogen form or ammonia nitrogen form has to be oxidized. This oxidation is done by a group of bacteria as known as nitrifiers. nitrifiers consists of nitrobacter and nitrosomonas. One converts ammonia to nitrite and other converts nitrate to nitrite. Those are autotrophic microorganisms. Once the entire amount is converted to nitrate we are not supposed to discharge them like that because excess nitrate can cause many problems. So if you want to remove nitrate we can go for various methods like ammonia stripping, ion exchange or biological methods.

Biological means denitrification. Denitrifiers are heterotrophic bacteria they utilize nitrate as the terminal electron acceptor so nitrate will be getting reduced to nitrogen and since they are heterotrophs so already whatever organic matter present in the system is removed we have to supply carbon source externally whenever we go for separate denitrification system.