Water Quality Management Practices

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Week-07

Lecture - 31

Activated Sludge Process: Description and Types

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. Today we will start the module 7 on the Aerobic Waste Water Treatment System 1 because in the second module also we will be continuing with the discussion about the aerobic treatment systems. In this particular lecture material, I will be discussing about the activated sludge process, its description and the different types. These are the concepts that we will be covering different activated sludge process description, the type of aeration provided in ASP, the quantification of microorganism in ASP, the types of activated sludge process and the description of the main feature of activated sludge process.

To start with we all know how activated sludge process works ok. We had a discussion in the last couple of weeks only we get to know about this term on and off. So, we know that activated sludge process is type where there will be one aeration tank and there will be one clarifier or secondary sedimentation tank. So, these two systems in as I said it will be called activated sludge process wherein the aeration tank majority of the organic matter will be converted into bacterial biomass.

This bacterial biomass will be sedimented by using by the forces of gravity in the secondary sedimentation tank that sedimented biomass is nothing but the sludge. Out of those sludge some of the sludge will be recycled back to the aeration tank in order to maintain the amount of microorganism present in the aeration tank and that is it. And the supernatant from the suspended secondary sedimentation tank, the treated effluent will be collected for further treatment or for further uses. So, this is how the overall activated sludge process works. One of the major component of activated sludge process is the aeration tank.

It means like you know you are having a tank where the you are providing some active aeration systems. So, it can be we discussed about the different aeration system in the last lecture. So, in different type of aeration system can be introduced here whether it be diffused, can be jet, can be surface aerators and all. So, I mean like our main motto is to increase the amount of air water dissolved oxygen in the water body and in order to do that we have to exchange the air from the atmosphere to the water body as much as possible in order to provide as much dissolved oxygen as possible into that water medium. And then that water will be transported to the transferred to the secondary sedimentation tank.

It can be it is in general it is a continuous systems that we normally follow sometimes it can be a plug flow system and very rare case it can be batch systems as well. Similarly the type of microorganism that grows here in the activated sludge process especially in the aeration tank because there is no medium that we are providing there. So, those microorganisms are staying in suspension. They stays in the column in the water column present in the aeration tank and because of the continuous agitation the aeration and agitation that is happening because of this it stays in suspension only. So, that means, these are the this is a suspended growth wastewater treatment process ok.

So, it is a aerobic biological suspended growth wastewater treatment process which uses the organic matter present in the wastewater and it converted into the bacterial biomass ok. This activated sludge why it is called activated sludge process is the activated sludge is nothing, but a mixture of microorganisms majorly different type of bacteria and some amount of protozoa and fungi is present and which actually maintain presence in suspension by providing adequate mixing either by employing the mechanical aeration or the diffuse aeration systems and all. This activated sludge what is the main purpose of it? To consume as much as organic matter as possible and convert it into their cellular biomass ok. So, what are the main part of continuous flow activated sludge process? First is the aeration tank where the organic matter is been stabilized by the action of active anaerobic bacteria under aeration system. Secondary sedimentation tank or the secondary clarifier, the biological cell biomass formed during the biochemical reaction is separated from the effluent of the aeration tank and the sludge recirculation and the excess sludge removal system.

So, what is happening there? The bacterial sludge settled in the sedimentation tank in some part of it it is recycled as we discussed and some part we literally discard or waste it and not waste it actually there is some sludge handling system through which actually we are first dewatering that sludge. So, that the it will be putting less it will I would say like you know less effort or by also it will take less space for its transportation also if we can dewater it as early as possible because the sludge anyway it contains huge amount of the water in it. So, the water portion if the moisture if you can remove it from the sludge it will give us additional advantage of ease of transportation plus we can actually handle it if we use it for incineration or a landfilling purpose whatever it is it will become much more easier ok. So, in case of activated sludge process what is happening? So, organic matter is coming into the picture some of them are they are they I mean like obviously, they are catalyzed by the bacteria and they get oxidized and form carbon dioxide and energy. This energy is being utilized for bacterial anabolism processes and they convert this remaining carbon remaining organic matter also in their cellular biomass.

So, what are the output that we get out of this process? One is the cellular biomass, second is the carbon dioxide gas and third is the energy ok. So, in general the mixed liquor from this adhesion tank is sent to the SST for settling and then in the settling it is recycled back and why it is recycled to improve the treatment efficiency in the process some why this is the major reason of recycling. The core of this process it is that it is capable of converting the organic matter represented by the biochemical oxygen demand or BOD present in the wastewater and it converted into carbon dioxide and the new cells. What are the factors in which this whole reaction the whole process will be depending on? First of all is the organic matter or the type of food ok. Second is flow of wastewater the more the flow of wastewater what will it will take less time the less time will be available for the microorganism to consume the organic matter.

So, it some amount of organic matter will escape from the system without being consumed by the microorganism. Dissolve oxygen in the aeration systems it is very important because you have to somehow maintain at least 1.5 to 2 milligram per liter of dissolved oxygen level, but DO level in the aeration tank in order to have those aerobic condition prevail. So, that the aerobic microorganisms can act on those organic matter and actually fulfill the job of this work ok. Rate of oxygen transfer is very important you can have suppose air supply system, but it is not efficient enough that will also affect the performance of the of your reactor obviously.

Second thing is like another important thing is the temperature there because the most of this activated sludge in aerobic microorganism they are mesophilic in nature. So, you can you try to make the temperature well in between the 30 to 50 to 45 degree Celsius temperature. If it is more than that in this thermophilic microorganism in thermophilic microorganisms can survive, but it does not solve the purpose of complete removal of organic matter or at least substantial removal of organic matter in from the system. And obviously, cyclophilic ones are also not very useful I mean like the temperature below 10 degree Celsius. So, you have to maintain somewhere between 20, 25, 30 is like optimum ok.

The 35, 40 is also good, but not more than up to a certain level. Nutrient availability it is not only the waste not only the wastewater you may sometimes need to supply some supplementary feed it is necessary. In case of aerobic treatment system it is necessary it is more like you know when you remember when we are doing the biochemical oxygen demand test we know that the wastewater may have some organic matter that that will be consumed by those bacteria, but still we were supplying some amount of trace elements or trace nutrient. Why we were supplying those trace nutrients is because in order to survive for the survival of those microorganisms. So, that here also you may need it like you may need to supply at as a supplementary nutrient source.

Then there is pH you have to control the pH obviously, it will definitely affect the cellular responsibilities going on inside the cell, inside the microorganisms of in your adhesion tank and the toxicity the toxic chemicals can also make a in the system. So, what are the factors that affect the microorganism growth? First of all the more soluble the food is the more the ease of consumption by the microorganism. So, definitely the like you know if you have a sugar solution and if you have a benzene solution obviously, like you know the sugar is much more easier for your bacteria to consume than your petroleum the benzene and all ok. So, you have a the food which is admitted to the adhesion tank it is normally we quantified by means of BOD we all know that that BOD is nothing, but a way of quantifying the organic matter present in your system. Sometimes COD also can be used.

So, majorly BODs are more prominently used and we need to know that the we need to provide some certain amount of time inside the reactor for water your waste water to stay. So, that the all the organic matter at least the maximum of the organic matter the efficient I mean like say more efficiently your the microorganism present in your adhesion tank can consume those polluted from the waste water the incoming waste water. So, it is very important to design it in a such a way that the retention time is just enough to consume the organic matter in its best possible rate. Sometimes and also this retention time obviously, depends on the flow the higher the flow lower the retention time. So, the lower the retention time the lower the chances of complete removal of organic matter from your from the waste water and there are other factors as well as I was discussing in the last slide, but anyway oxygen is obviously, the prerequisite for or aerobic microorganism to break down this substrate because they go for aerobic respiration process.

And sometimes this DO concentration like you know can be low as low as 2, 3, 1.5, but it should not be below 1.5 at any course of time because it will make the system anaerobic in nature and anoxic in nature and because of that those anaerobic bacteria will not be able to survive. And for them the optimal temperature is the mesophilic temperature I was as I was discussing in the last slide and also the pH range of 6 to 9 is preferred, but in to be more sure the it should be better to have 6.

5 to 7.5 pH present in your aerobic treatment system in your aeration time. How the microorganism is been quantified as if you remember we discussed about the solid analysis. In the solid analysis we have this volatile suspended solid by means of volatile suspended solid we can easily quantify the amount of microorganism present there it is like a passive means of quantifying quantification of microorganism present in your systems. It can be live it can be dead, but in general that is that is the one of the crudest time in like the and also one of the efficient method of one of the efficient method in case of wastewater engineering for quantification of the microorganism present in your aeration tank. So, that you will make sure that that particular VSS is maintained in your aeration tank.

In order to maintain that particular VSS we add some amount of sludge back to the system and we call it mixed liquor volatile suspended solid because we are mixing the excess sludge as well then it would be called mixed liquor volatile suspended solid. This MLVSS inside aeration tank should be of a certain value if you want to run the system with a optimum performance. So, because if you somehow increases somehow decrease it does not make sense because the amount of food theoretically which is coming into the picture are almost the same theoretically ok. The last is when we are going to go for design purpose we have to design it for a certain BOD level. We design it for say like maximum BOD that it can receive and based on that we design it, but sometimes it is not necessary it is not efficient to design it for the maximum BOD you receive because that means, that most of the times the actual food will be much lesser than the design one.

So, because of that your system will be in at stress ok. So, there are different factors those affect all these things. So, another important thing is like you know when we go for total mass concentration of the sludge it is represented by mixed liquor suspended solid or MLSS. This MLVSS by MLSS ratio for the activated sludge process sludge is generally remain and 0.

7 to 0.85. So, on an average it is 0.7 to 0.85 that means, the total sludge total suspended solid which represents the total suspended solids or mixed liquor suspended solid which represents the total amount of sludge present out of them the volatile percentage of that sludge actually represents the organic fraction actually represents the biological matter ok. So, this biological matter is nothing, but those biomass ok, this bacterial biomass.

So, this is how you quantify. So, MLSS represents the total sludge kind of you know quantifying the sludge concentration and MLVSS is actually gives you a exact almost the exact picture of the amount of biomass present in your system. Then there comes the loading rate it is very important for you to understand the loading rate I think you already know all these things because we had we use this term couple of time in our earlier lecture also. So, majorly the organic matter loading rate it applied to a reactor where you know we supply some amount of organic matter in terms of BOD ok. So, BOD per unit volume of reactor per day and which we call it volumetric loading rate or organic loading rate. So, there is another type of loading rate which is also quite famous it is also a type of organic loading rate or we call it food to microorganism ratio.

We also know that what is food to microorganism ratio it is more like you know the more the food the better the performance right. So, it is more like that. So, food to microorganism ratio is very important and how you justify the food quantify the food I would say the amount of organic matter comes into the picture. So, what is the total amount of organic matter that is coming into the picture over time the flow rate inflow rate multiplied by the BOD of that inlet wastewater the influent wastewater that will give you the exact value of the food that is being introduced into the system into in your aeration tank over time. And how you can quantify the V I mean like the sorry I mean like the M the microorganism.

The microorganism means the at any course of time what is the total amount of microorganism present in your system. How you are going to quantify it? First of all you need to know that what is that. So, it is more like you know how you are going to quantify the population. You need to know the total say like in this particular case you need to know the volume multiplied by amount of microorganism present per unit volume. So, if you multiply it you will get the total microorganism it is more like that.

So, you will multiply the V the total volume of your aeration tank multiplied by the x t. So, the total volume multiplied by x t is what the this is the MLBS concentration of your aeration tank. So, MLBS concentration of aeration tank multiplied by the volume you will get the total microorganism. So, total food is known to us it is a Q into BOD the inflow rate multiplied by BOD divided by V into x t represents the F by M ratio

Volumetric loading rate, $kgBOD/m^3\ day = (Q \times BOD \times 10^{-3}) /V$

F/M, $kgBOD/kgVSS\ day = Q \times BOD/(V \times X_t\ )$ ok. Is not it easy? It is just try to understand the concept.

Then there comes the SRT or the solid retention time or the mean cell retention time.

That means, the to discuss about it in a very layman's language it is like for how long your sludge is being like you know any solid particle that is there in your in the system like you know for how long it stays there in the system itself ok. It can be quantified by select total amount of MLBS's present in your aeration tank divided by the amount of MLBS's that it you are losing over time.

$$SRT = \frac{\text{Total kg of MLVSS present in aeration tank}}{(\text{kg of VSS wasted per day} + \text{kg of VSS lost in effluent per day})}$$

From there you can easily calculate the SRT. So, that means, the total kg of MLBS's present in the aeration systems that means, V into x and divided by you have the kg of VSS wasted per day and kg of VSS lost in effluent per day.

So, the wasted per day you remember in the secondary sedimentation tank some of the sludge is getting wasted and some of the VSS some of the bacteria very tiny tiny bit of microorganisms can also leave with the supernatant effluent also. Because it may stays in suspension it does not settle all of them the all of them does not settle well and some of them actually stays in suspension and goes away with the supernatant that is called the effluent loss through the effluent ok. So, from there you can easily calculate the sludge retention time solid retention time or mean cell retention time. Then there come the sludge volume index it is the volume of the sludge in milliliter occupied by 1 gram of dry weight of suspended solid measured after 30 minute of settling ok. So, that can be calculated by we call it SVI calculated by the settled sludge volume multiplied by 1000 divided by the MLSS of your system.

$$SVI\left(\frac{mL}{g}\,of\,SS\right) = \frac{Settled\ sludge\ volume(mL)\ x\ 1000(mg/g)}{MLSS(mg)}$$

Then there come the quantity of returned sludge. The quantity of returned sludge is to be determined based on the concentration of concentration that is to be maintained in the aeration tank and based on that you supplies 20 to 100 percentage of your sludge I mean like sometimes even more like you know you like put it back to the unit again aeration tank again. So, that is called the returned sludge ok. So, if you see sometimes even more than 100 percent how it is possible you may confuse like how it is possible to return more than 100 percent of the sludge. It does mean some amount of sludge over time say you are supplying 80 percent of the sludge as a as a returned sludge.

Some 20 percent it is actually you are either you are handling it in the sludge handling unit or you actually you are using it some other purpose. So, from there also sometimes it may require that your demand is quite high and aeration tank needs more amount of sludge then it actually overflows through this I mean like there it we waste it through the secondary sedimentation tank. So, then 100 percent of the sludge is being recycled plus some amount of sludge which were earlier we are storing like over the last few like you know near past. From there also we will take some of the sludge and we actually recycle back to the aeration tank to maintain the amount of MLVSS inside the aeration tank system in the biological waste water treatment system. So, you understand right what is this returned sludge and how we normally place it back to the system again.

Sludge bulking it is a very important phenomena happen in the secondary sedimentation tank what happened? We keep the secondary sedimentation tank so that the because of the flow because of the forces of the gravity this biomass will actually settle down and we can easily collect it in the form of sludge. But in some cases what happened because of the presence of the filamentous bacteria present in your sludge and all it may still stay in suspension. Though you are making it complete idle and you have some certain amount of time you leave the water unagitated. So, you are expecting that some of those sludges will actually those I mean the particle those component of this waste water system will definitely goes down and the sediment in the bottom, but it will not happen. So, when it would not happen that time it is called the sludge bulking phenomena.

In case of sludge bulking phenomena you will lose a huge amount of active biomass through the effluent. So, that is a problem. So, we our target is to reduce the sludge bulking phenomena. So, there are there are different ways of actually tackling the sludge bulking phenomena. We use some kind of like you know coagulant sometimes we reduce the chances of having filamentous microorganism into the in the systems and we and also there are certain cases we change the pH and actually maintain the reduce the sludge bulking that way as well.

So, next important thing is the mixing condition. In the plug flow tank the food to microorganism ratio and oxygen demand is highest in the inlet end of the aeration tank and then it will progressively decrease over time like when it slowly approaches towards the outlet or the end of the aeration tank. Wherever in case of completely mixed system the F by M ratio and the oxygen demand will be uniform throughout the tank ok. So, the one that we are going to design we are going to talk about more is the completely mixed system ok. So, it will be easier for you. The flow scheme in general the outline options in the wastewater addition is in aeration tank then it is a single point or inlet or multiple point is also possible.

Then the sludge return from the solution tank can be also have a single outlet or multiple outlet and you can choose it like you know the amount of this return sludge for the proper process control and higher volume of management. And diffused air system or in a compressed air distribution can be uniform or tapered along the tank length to match the oxygen demand with higher air supply at the inlet gradually decreasing towards the outlet depends like you know depends upon the type of system. So, we are going to discuss about it in next slide I mean like next lecture material that what are the different types of activated sludge process based on this process parameters and all. So, even here only actually we are going to get to know a bit about it. First of all the completely mixed systems the uniform concentration of pollutant throughout the reactor, better overload and toxicity handling capacity in case of completely mixed and suitable for the industrial waste water in the sewage.

In case of plug flow it is predominantly the longitudinal dimension of the aeration tank is more efficient than the completely mixed ones and it produces better settleable sludge and the oxygen demand also decreases along the reactor and the DO concentration increases and along the reactor, but it has a very lower capability to handle the shock load. Whereas in case of taper duration taper duration what is happening you know suppose you have a long like you know rectangular tank aeration tank and the very beginning you have a more holes in the aeration unit to provide more amount of oxygen, more amount of air at the beginning then the next stage. So, in the beginning the distance between two gap in the aeration unit are like very less. So, because of that the aeration is happening in a much of higher rate the air flow rate is much higher air inflow with time the distance are distances in the pipe like you know in between two holes from through which the air is actually coming out of the system.

So, aeration systems are actually quite long. So, I mean like the length is quite high quite more. So, because of that what is happening the less amount of oxygen less amount of air transfer thing is going on which is actually optimal because in the beginning only the when the wastewater is introduced to the system that time only we need more amount of oxygen. The more you go towards the end we do not we do not need that much of an oxygen as such. So, based on that only there is some modification you can do in the design and it will be called tapered aeration activated sludge process. There is tape aeration systems as well where you introduce the wastewater not only from one side, but with at different position.

So, it can be just before the effluent line just before the effluent line when it goes out of the aeration tank and comes in contact with the secondary sedimentation tank. There also you can introduce this kind of system ok. This is called the tape aeration system where more or less homogeneous oxygen demand is there and food to microorganism is maintained within the limited range. Majorly we discussed about it like the surface aerator systems how that how it works in the last slide only last I mean like lecture only. And we also will get to know now that about the classification based on the food to microorganism ratio or the mean cell aeration instance.

There are conventional activated sludge process, there are completely mixed activated sludge process, there is extended aeration systems and all. We will be discussing about it because it is better to discuss at certain point of time like in couple of slides after we will be having a proper table. In that table we will be able to understand the different type of activated sludge process with its different characteristics phenomena. So, the whenever we look into this table it will be much more easier for us to grasp the difference between the all this type of different type of ASPs and how it works. Based on the physical configuration of the aeration basin it can be either taper aeration, step aeration or completely mixed system.

Majorly how what are the major feature of conventional ASPs? The flow model adopted in aeration tank is plug flow type. The influent wastewater and the recycle recycle sludge are aerated for about 5 hour in the sewage treatment. So, aeration tank has a hydraulic retention time HRT of around 5 hour. The effluent and the recycle sludge are mixed by the action of the diffuser or the mechanical aerator placed in the aeration tank. Constant rate of aeration is provided throughout the length of the aeration tank.

During the aeration period the adsorption flocculation and the oxidation of organic matter takes place. If by ratio normally stays between like 0.2 to 0.4 kg of BOD per kg of BSS per day and the volumetric loading rate should be 0.

3 to 0.6 kg of BOD per meter cube per day. The mixed liquor suspended solid concentration will be somewhere between 1500 to 3000 and mean cell residence time will be 5 to 15 days in general. Mean cell residence time is nothing, but the sludge retention solid retention time. Hydrodynamic retention time HRT should be somewhere around 4 to 8 hour for sewage treatment and higher HRT is required for treatment of industrial wastewater having higher effluent BOD concentration. So, it takes more time.

The sludge recirculation ratio normally lies between 0.25 to 5 percentage 0.25 to 5 that means, almost quarter to half of the wastewater that goes into the secondary transmission tank comes back again into the system to maintain the MLBS concentration in the aeration tank. Tapper duration you remember this you whenever when check out this picture in this left one. In that picture whatever see the distance between the aerator at the beginning it is much narrower with time it becomes quite wider. So, this is called the tapper duration systems that is what I was telling.

At the beginning when the influent comes into the picture into the reactor this tapper duration systems we normally design. Then there come the step aeration systems where the wastewater see the influent is introduced at a different part of the treatment aeration tank. Though the aeration is same, but at the different position when you are introducing it you are actually literally playing with the treatment efficiency and it actually there are instances that it actually gives better performance. Then there comes the completely mixed activated sludge process. In case of completely mixed activated sludge process the flow regime in the aeration tank is completely mixed and the wastewater is like normally to be treated in is distributed along the return sludge uniformly from one side of the tank and the effluent is collected from the other side of the tank as you can see from the picture.

And then we have the better capability of handle toxicity and the fluctuation in this kind of completely mixed ASPs. You see this table please write it down in your notebook this table it is very important. Whenever you are going to choose that which type of activated sludge process is best you have to understand this design recommendations first. Based on the F by M ratio different type of ASP has a different F by M ratio as you can see from the first row second row of the this table. Where the activated sludge process is completely mixed taper direction the step aeration system the volumetric loading rate, mean cell residence time, mixed liquor suspended solid, hydraulic retention time, sludge retention recirculation ratio all of them are varying over like different type of activated sludge process.

So, based on your expectations and the type of design that you need you can choose among them and you will get the efficiency based on the available option that you have chosen. In case of extended aeration ASPs there is another type of system where we keep it for long we aerate it for long enough time. So, when it when we aerate it for long enough time what will happen all the product whatever the organic matter is there it will definitely be consumed rather the micron resource present in the system they will start having their endogenous decomposition ok. It also started happening and it requires a very low organic loading rate and it can have a very prolonged aeration time. In general very low excess sludge generation is happening in this case because all the organic matter is efficiently converted into biomass and those biomass is having like you know good dewatering capabilities and all.

Secondary clarifier in general it is not used and secondary clarifier is designed with a lower hydraulic loading rate to ensure the maximum sludge retention and all. And it is suitable for small capacity plant of say like less than 3000 cubic meter per day. This is a very important comparison between the conventional ASP and the extended aeration ASP. In case of conventional ASP primary sedimentation unit is present in case of extended it is not there.

In case of conventional the F by M ratio is 0.2 to 0.4 in case of extended aeration it is 0.05 to 0.15. Likewise you know all the values are differing are differ to definitely differ like drastically in some cases as you can see from the sludge age and some cases it is like very minor like the removal efficiencies and all like the organic matter removal efficiencies and all. So, as I was saying there are some more differ like you know there are some more designs of activated sludge process like the contact stabilization process where you can see there are like two aeration tank I would say like you know first aeration tank it acts like you know like a adsorption properties of activated sludge.

It only involves the organic matter to be there for like almost 30 to 90 minutes. Then another aeration of a return sludge is happening after the secondary sedimentation tank for more than up to 3 to 6 hour resulting in a enhanced capacity compared to the conventional ASPs and all. In case of oxidation ditch it is a extended aeration activated sludge process where aeration tank is constructed in the ditch shaped or the oval shaped and one you see this both the like you know thorn like structures this is oxidation these those are nothing, but the aeration aeration devices. It can be surface aerator and another one can be diffused aerator. So, it will let the water flow from one side to another and because of that like this is called the oxidation ditch. So, perfect so, we understood different types of activated sludge process we understood the what how it works and what are the major components how what are the control parameter of activated sludge process.

We also understood variety of aeration methods and different ASP variants as well. So, I hope this information will be very handy to you when you are going to design it in coming slide only different type of activator sludge process and all. So, this is the references. Thank you so much see you in the next video.