Wastewater Treatment and Recycling
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Lecture – 31
Biological Treatment of Wastewater: Activated Sludge Process

Hello friends so, this week. So, for we have been discussing about the various aspects related to the Biological Treatment of Wastewater, how the microorganism attack the organic compound for their energy or carbon needs and then how they grow. So, all the basic concepts we discussed and this lectures, we are going to talk about one of the most popular unit, which are typically like conventionally used across the world in the sewage treatment plants is activated sludge process and that is what we are going to discuss in this particular lecture.

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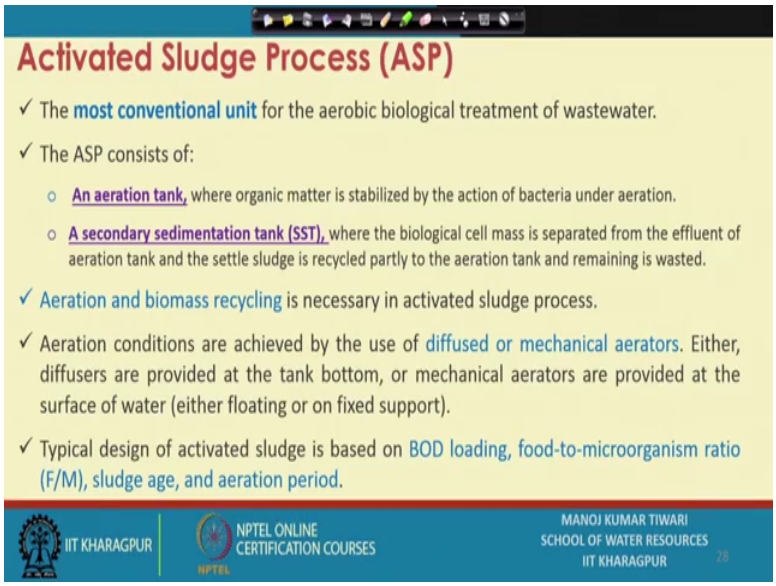

So, what is activated sludge process or ASP which is commonly known as ASP according? So, this is actually there as we are saying it is the most conventional unit which works on a aerobic, like aerobic principles of wastewater treatment. So, the organic matter present in the water or the BOD you can say represent in the water is actually degraded or reduced by the principle of aerobic degradation or aerobic decomposition, in a system in a reactor or in a unit which typically supplies oxygen, because it is a aerobic system. So, it insurance the supply of oxygen keep the content

more or less in the mixed state and allows bacteria to grow in the suspension. So, this is a suspended growth system.

The typical activated sludge process is actually a suspended growth system. So, activated sludge process typically consists of two separate chambers, or two separate tanks we can call that. So, there has to be a aeration tank which is where the organic matter is stabilized or decomposed by the action of bacteria under aeration.

And then there is a secondary sedimentation tank, which is also known as secondary settling tank or secondary clarifier, where the biological cell mass is separated from the effluent which is coming from the aeration tank. And actually the sludge is settle down at the bottom while effluent crosses from the top; find its way from the top. So, they this is essentially a separation process where the solids are separated from the mixed solid liquid state.

The aeration and biomass recycling is generally necessary for activated sludge process. So, aeration conditions are achieved means, for purpose of providing aeration or supplying aeration, there are two ways either diffused aerators are used or mechanical aerators are used. So, diffused aerators provide the like, if you have this tank and you have put in a diffuser air.

So, you pump air from here and then the air is released from the bottom and is actually your waste water is here in this tank. So, air bubbles finds its way and that way air keeps in the mix condition in this chamber. So, that is the diffused aerator, while mechanical aerators are provided usually at the surface of the water. So, if you have aeration tank you provide basically device with mechanic paddles and all that and allow it to makes. So, as this rigorously makes as it actually ensures the supply of oxygen there.

So, this could be either floating or with the fixed support. Now, the typical design of activated sludge processes are based on the BOD loading food to microorganism ratio, sludge age and the aeration period. So, for how long we need to aerate for how long we need to retain sludge in the system, what has to be the appropriate food to microorganism ratio as we are discussing that is a important parameter what is what has to be the organic loading or BOD loading in the system. So, all these things are considered while conceptualizing or designing the activated sludge systems.

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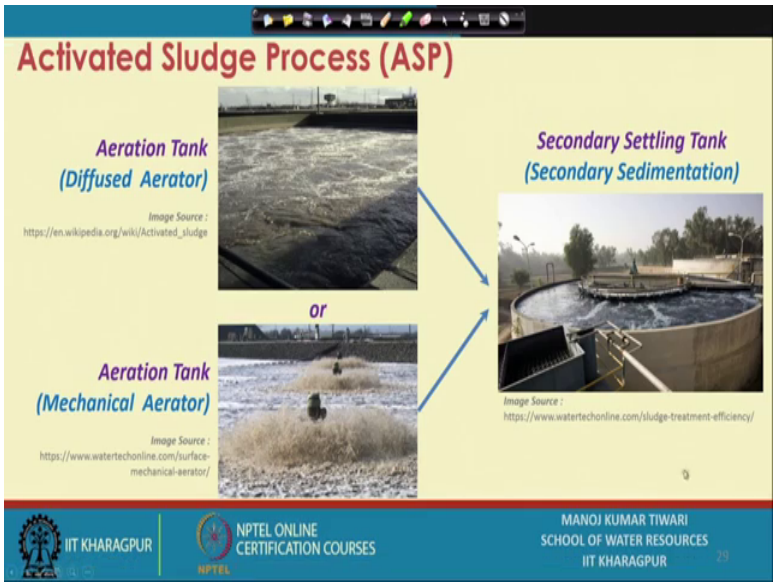

So, in a nutshell what we are discussing so for we will have a aeration tank. Now, this aeration tank could be either of the diffused type like this one is the diffused type aeration. So, we cannot see anything on the top just seeing the bubbles coming out, so, the content remains in the mixed state and significant air supply is insured here. So, this is a kind of diffused aerator system or, we can go for the mechanical aerators as we are discussing which are kind of devices put in the pedal. And then their rotate here, frequently ensuring the supply of oxygen in the water. So, these are kind of mechanical aerators these are diffused aerator.

So, we will have a aeration tank which would have either of these two mechanisms, typically either diffused aerators or mechanical aerators and then the water traditionally come to this, or this any of the route which is being followed. So, water will the water means the effluent from the primary sedimentation. So, primary settling has already taken place and then the flow is connected to either of these two systems either a diffused aerator mechanical aerator and from here, onwards it is directed to a secondary settling tank, or secondary clarifier or secondary sedimentation.

So, what happens in a tank like this the mixed leaker here, or mixed liquid is transferred here and then it allows this thing to get settle and that is eventually what happens that the overflow from the top of the water is collected in a channel while the sludge from bottom is taken out. So, that is what typically happens in activated sludge process.

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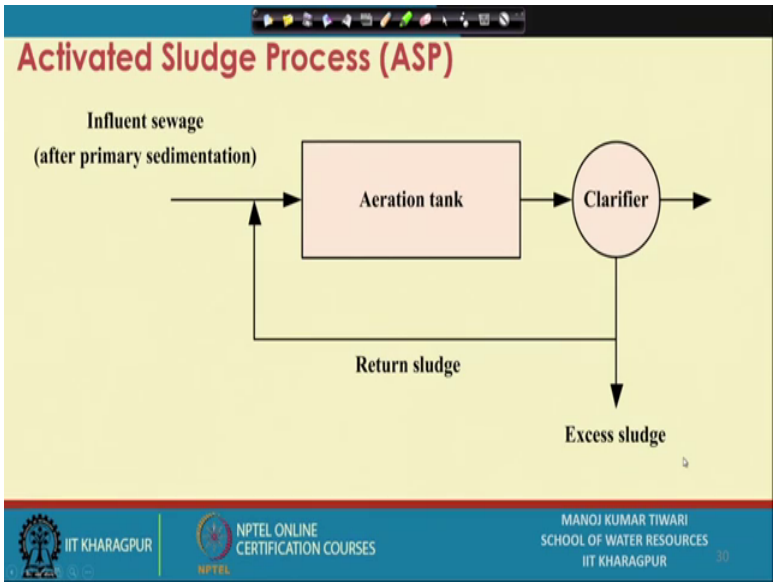

If we see the more conceptual diagram that way. So, we will have influent sewage after primary sedimentation coming into a aerator system. And, then there is a aeration tank where the mixing aeration and oxygen supplies takes place it goes to a clarifier, from clarifier the influent means, this is your treated water or treated sewage; treated means, treated from this unit not entirely treated. So, that way you can say it maybe effluent instead of the treated sewage. So, this is actually the effluent, this is your influent.

So, here the water goes through the influent and the sludge settled sludge is collected, out of the settled sludge part of sludge is wasted, which is actually excess sludge while the part of sludge, which typically like some somewhere between 25 to 50 percent around that of the sludge is again recycled back to the aeration tank aeration system.

So, that is the return sludge component, this recycling is advantageous in terms of, this is actually advantageous in terms of managing the required amount of biomass in the system. So, as we were discussing the difference between the suspended and attached growth system one of the major differences, which we are discussing in the last lecture as well. That the attached growth system are, because the microbial growth or microbial growth is attached to a media the biofilm which is formed is attached to something.

So, the water flows through that and the biomass retains in the system whereas, in suspended growth system, because the microbial mass is also suspended in the water is actually in the mixed with the water. So, when water flows from here, it actually takes

those suspended mass as well the which typically we refer as say volatile suspended solid.

So, it takes the volatile suspended solids or biomass also along whether it, which eventually goes to the clarifier. Now, if we do not recycle so, lot of biomass which is being produced is actually leaving the system and there would not be sufficient biomass left here. So, in order to ensure the significant concentration of biomass in the system whatsoever comes here, part of that is recycled where the excess sludge is just wastage. So, that is what the conceptual process that takes place in activated sludge system.

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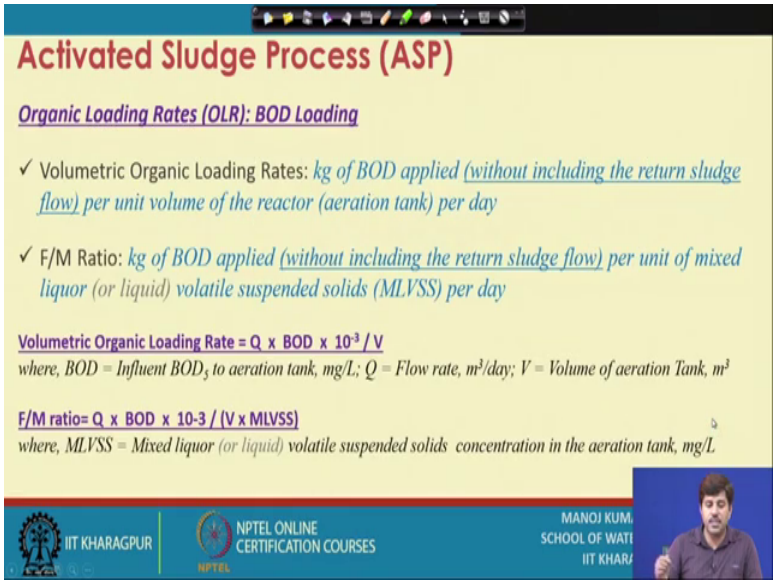

Now, there are certain things based on which we design or we conceptualize the activated sludge process certain parameters. So, one of the important parameters is organic loading rate or BOD loading. So, how much BOD is being loaded or how much organic matter is being loaded or is being supplied to the activated sludge process. So, the volumetric loading rate there are two types of such loading organic loading we can say. So, one is the volumetric organic loading rate, where we quantify the amount of BOD applied or kg of the BOD applied per unit volume of the reactor.

So, for in a unit volume of the reactor how much BOD is being fed, now unit volume of the reactor, here we considered the volume of aeration tank only. In because, there is a inherent assumption in activated sludge process that the reaction or the degradation

process takes place only in the aeration tank, because that is where we are so, feeding in oxygen, that is where we are providing adequate environment for the reaction.

The role of the secondary clarifier or secondary settling tank is just to separate the solids from the liquid and no reaction no degradation nothing happens other than this separation process, in the secondary sedimentation tank, that is the basic assumption which is taken in the activated sludge process. So, in light of that assumption, whenever we calculate such loading and all that, we considered the volume of aeration tank only because that is where the degradation or decomposition is taking place, it is not taking place in the secondary sedimentation tank. So, we do not considered the volume of secondary sedimentation tank for our calculation or design purpose.

So, that is why when we are talking about the organic loading rate of volumetric organic loading rate, we do not include the volume of the secondary sedimentation tank and we do not include the return sludge flow also. So, what primarily we include is that how much inflow is coming in the, in your activated sludge process.

So, if this is my aeration tank, this is my secondary settling tank there is basically recycling. So, we do not consider this as a inflow, because ultimately you can see that this entire thing is just one unit this is what we refer as ASP. So, for this one particular unit what is the inflow of the BOD, that is what we considered per unit volume of the reactor and volume of the reactor we considered this only.

So, that is what is typically how it is considered, then there is another form of organic loading rate, which is your food to microorganism ratio; that means, how much BOD or how much organic matter is applied per unit of the mixed liquor volatile suspended solids. Or per unit of the biomass available, this mixed liquor volatile suspended solids which is typically referred as MLVSS.

So, there are certain terms which are frequently used in here, those terms include there is we already have talked about while talking about the parameter TSS and VSS, which is total suspended solid and volatile suspended solids, we also use MLSS which indicates the mixed liquor suspended solids.

So, what is the suspended solids in the mixed liquor or mixed liquid. So, in aeration tank when there is a mixing happen. So, we say that it is a suspended growth process. So,

bacteria and water and organic matter everything is remains in the mix states suspense on a state.

So, when we take this water as it is or a unit volume of this water and try to monitor the solids in this, we call that mixed liquor suspended solids. There is another term which is MLVSS mixed liquor or mixed liquid either way, it is some references it is pronounce at mixed liquid some references it is pronounced as mixed liquor. So, the MLVSS is another term which is mixed liquor volatile suspended solids. So, this is the fraction, like this here, you can it does not say total suspended solid, but it essentially means that mixed liquor suspended solid or mixed liquor total suspended solids, where as this is the volatile part of the suspended solids.

Now, what this solids means in terms of activated sludge process so, as we were just discussing that the inflow to the activated sludge process is after primary clarifier or after primary settling tank. So, majority of the inorganic solids majority of this yield clay, or those kind of suspended materials has already been removed in the primary sedimentation scale. So, the primary settling has already removed majority of the inert, or inorganic solids and in a suspended form whatsoever is they are in the activated sludge process is primarily bacteria.

So, there is some initial cd's be provided anyway and then there is a growth of microorganism that takes place and these microorganisms are also suspended solids, because they cannot get dissolved in the water, they remain in the suspension and that is why we call it suspended growth systems.

So, since they remain in the suspension, these microorganisms are part of a solid matrix for the water and so, the when we measure, or when we monitor the solids in a activated sludge mixed liquid or mixed liquor system, we what we get predominantly is the microbial biomass. So, that is why this VSS we can call that are even MLSS, or MLVSS is basically considered as the indicator or measurement of biomass present in the system, because we have already removed other suspended solids already. So, whatsoever present in the system is predominantly microorganisms.

Now, MLSS which is, even if there is let say some solids left, some inorganic, or inert solid lefts that will come in the MLSS, but if we measure MLVSS basically so, because

the nature of the microorganisms, they are made is volatile. So, they ones you heat that water at 550 the even the microorganisms are going to get vaporize.

So, what MLVSS gives is the more precise estimation of the microorganisms considering that even if there are some inert solids are suspended materials left in the system they will accounted in MLSS, but not in MLVSS because on the volatile part you have already remove the suspended organic, or inorganic materials in the primary settling tank and the volatile materials that are left are primarily the microorganism.

So, this MLVSS that way is considered as a measurement of microorganisms, or measurement of biomass or bacteria present in the system. So, the food to microorganism ratio is essentially the amount of BOD applied or amount of organic matter in flow coming into the system per unit MLVSS per day. So, in a day for the unit amount of microorganisms, what is food to microorganism ratio m is stand for micro organism that is biomass, which is represented by MLVSS here and F is the food which is represented by BOD.

So, the ratio of BOD to MLVSS in a day is basically the F by M ratio, then there is volumetric organic loading rate from here, we can get is actually the amount of BOD applied. So, how much BOD is applied if Q is the discharge so, Q into the so Q into the BOD will be the mass of BOD and of course, it BOD is in milligram per liter. So, we can multiplied with 10 to the power minus 30 to get milligram per meter cube as typically this is let say in meter cube per day and this is in milligram per liter.

So, if you multiplied with 10 to the power minus 3 so, this total becomes actually in the milligram per meter cube and that way you can see that meter cube get is cancel and it eventually becomes milligram per day and if you multiplied with the volume of the reactor. So, you are multiplying that way so, that is giving you the volumetric organic loading rate over here.

Similarly, F by M ratio can be obtained as Q into BOD into 10 to the power minus 3; that means, total organic load coming in into the volume and m l v S MLVSS. So, volume of reactor and if you multiply with the concentration so, this will give you the mass of the microorganisms or biomass present in the system and this is mass of the food coming into the system. So, this ratio gives food to microorganism ratio that way.

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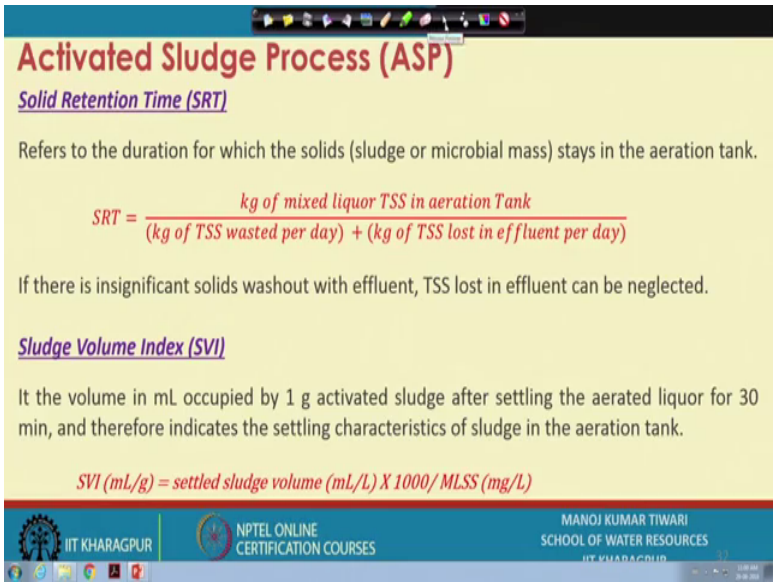

Now, there are few other terms solid retention time which is the SRT, this refers to the duration for which the solids which primarily sludge or microbial mass, we are talking about stays in the aeration tank. So, this SRT typically is actually the kg of the mixed liquor total suspended solids in the aeration tank. So, how much total solids present in the tank at any given point of time or in a day and kg of the total solids wastage per day plus kg of the total solids lost in the effluent. So, if you quickly see again this is your aeration tank, this is your secondary settling tank, this is the amount of recycling. So, if you consider this as a your activated sludge process thing.

So, how much solid present in here which is actually under reaction, this if you divide this total mass with the rate at which the solids are being wastage. So, some of the solids which is going out with this route divided by some of the plus some of the solid divided by this route. So, if you add these two so, this what you get is the total amount of solid being wastage in a day and the total amount of solid present in the system. So, for say 100 kg just roughly 100 k g is present in the system over here. And you are wasting 2 kg per day from this route and say 3 kg per day from the this route.

So that means, you are total 5 kg per day solids you are wasting. So, if you divide 100 by 5, because total 100 kg and in one day you are wasting 5 kg of the solids so; that means, typically solid is going to retain their for 20 days. So, this becomes the solid retention

time which typically refers to the duration for which the solid is going to stay average duration for which the solid is going to stay in there.

So, that is what is yours solid retention time, there is another term which is MCRT, mean cell residence time which is the similar term in fact, but this solid is normally for the total solids present in the system where as MCRT or mean cell retention time is for specifically microorganisms.

So, they are major in a similar way the only difference is there in MCRT we do not considered TSS, but we take VSS or MLVSS here, MLVSS or VSS. So, instead of like considering the total solids we considered just the mixed liquor volatile suspended solids are the volatile suspended solids, which has more appropriate indicator for the biomass that gives us the mean cell retention time. There is another term sludge volume index which is the volume in mL occupied by 1 gram of activated sludge after settling in the aerator liquid for 30 minutes. So, this is the standard protocol, we allow one gram of activated sludge to settle for 30 minutes and see how much volume it is occupying.

So, the less volume less means as less the volume it occupies, because amount of the sludge is same. So, if it occupying less volume; that means, it is a compact sludge it has a good settling characteristic and therefore, it is a compact sludge and it is better to have a less sludge volume index. If you are having a high sludge volume index; that means, the sludge is not that dense it is sort of fluffy and it will not have good settling characteristic. So, SVI or sludge volume index is given as milliliter per gram means how much volume it is occupying for 1 gram of sludge. So, this the settled sludge volume into 1000 into MLSS so, how much MLSS we have taken and how much volume to how much volume is settle. So, that gives the sludge volume index.

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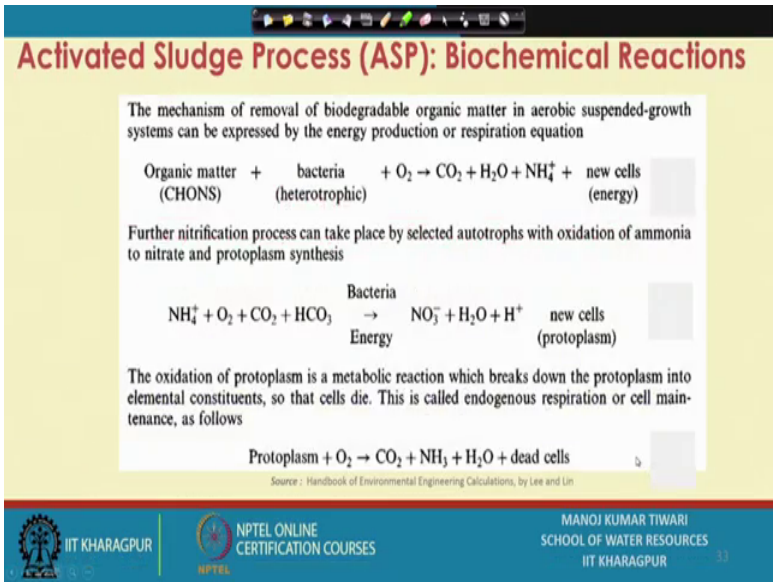

If you see the biochemical reactions that takes place in a activated sludge process. So, the mechanism for the removal of biodegradable organic matter in this aerobic suspended growth system, can be expressed by energy production or respiration equation, which we discussed in the earlier. So, organic matter here which is made of CHONS primarily so, this organic matter reacts with the bacteria with the oxygen produces CO 2 produces H 2 O may produce ammonia and generate new cells.

The nitrification could also occur although as we were discussing in the weak when we are talking about the natural at innovations. So, nitrification can also take place; however, it is a delete process so, if we have to increase the residence time for nitrification if you want it to be occur, but if it occur so the amount of nitrogen present with oxygen CO 2 and bicarbonate and that produces the nitrate, in order to like it oxidizes ammonia to nitrate and produces more new cells of the nitrifiers.

So, there is a oxygen requirement for nitrification as well, oxygen requirement for carbonaceous BOD removal as well. The oxidation of protoplasm is again a metabolic activity, which break downs the proto this protoplasm into elemental constitute so, that sells die. So, this is called endogenous respiration and this endogenous respiration or cell maintenance also takes place and the reaction required for that is this. So, that is how we basically get, these are the common processes that typical takes place in activated sludge system now.

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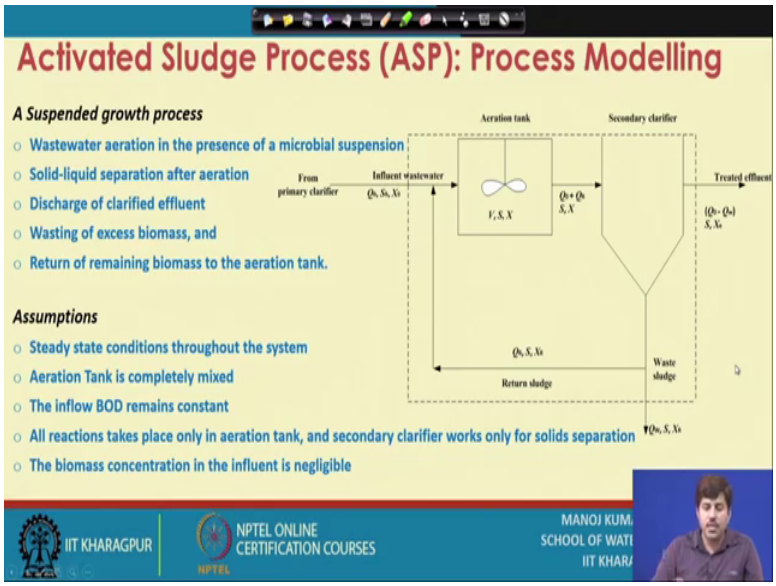

If you see the how the activated sludge process is designed or model so, activated sludge process is typically a suspended growth system, where waste water aeration is presence in the presence of microbial suspension is achieved, solid liquid separation is achieved after aeration the discharge of the clarified effluent or treated effluent goes out from the secondary clarifier. The excess biomass is wastage and remaining biomass is return or required biomass is return to the aeration tank. So, this is the process that takes place, for modelling purpose or for designing purpose we take certain assumptions and based on that only we design the systems.

So, those assumptions include there has to be a steady state conditions throughout the system. So, that is the first thing we assume, because SP is normally operated in a as a continuous reactor continuous flow reactor and continuous flow reactor. So, we assume that the steady state is throughoutly maintained in all in both the units over here. So, steady state maintain means that the characteristic of influent is not changing with time that becomes another assumption. So, the influent BOD remains constant, steady state condition is assume throughout the system, we considered this aeration tank as a completely mixed system.

So, we do not assume any plug flow kind of thing in aeration tank and we considered that volume whatsoever is the content in the aeration tank, that is what is leaving the system and that is why like, when we go on doing this mass balance thing we consider

that whatsoever is the concentration of substrate or concentration of the biomass, it will be the same concentration of sub or substrate and biomass in the outflow. As we discussed earlier during our deliberations over the plug flow and continuous systems during the mass balance analysis.

So, all reactions takes place only in aeration tank, as we were discussing earlier also. So, that is again a very important assumption that all reactions takes place only in aeration tank. And secondary clarifier works only for the solid separation, it does not take part there is no reaction there is no nothing happen. So, that is why when we compute the volume, we primary compute the volume of aeration tank depending on the reaction kinetics.

The biomass concentration in the influent is negligible that see another assumption, which is usually taken that the biomass which is entering the system along with this, along with the water is almost negligible and whatsoever biomass available in the system that and the recycled or returned sludge is the one which are actually doing all this like degradation, or decomposition process in the aeration tank. They are the one which are involved in this process in the aeration tank and there is no inflow of biomass. For most of the time design purpose even the wastage of the biomass along with the treated effluent means the sludge wash out if you say that is also considered nearly 0. So, that is another assumption which is often taken.

So, X 0 and X e is often considered as 0 and this thing happen. So, what happens if you quickly see this is the amount Q 0 Q or Q 0 is the amount which is actually coming the discharge S 0 is initial substrate concentration or BOD, initial BOD were typically you say and this is the initial biomass which is actually 0. Now, in aeration tank this reaction takes place V is the volume of the tank, S is the substrate concentration or BOD in the tank and X is the biomass in the tank. Same leads out and then it goes to the clarifier and from clarifier a part of discharge which is Q 0 minus Q W is actually goes in out where as the some part of the discharge which is actually Q W plus Q R comes at along with the sludge out of this the Q W discharge is wastage while Q R quantity is recycled.

Now, since this Q R quantity is recycled so, net inflow to the aeration tank becomes Q 0 plus Q R and not just Q 0, Q 0 is coming here Q 0 flow is coming from here and Q R flow is coming along with the biomass is coming from this side. So, total amount which

is actually going in the aeration tank it is Q 0 plus Q R and this is since it is a steady state systems. So, this amount which is going that amount will leave the system. So, what leave the system is again Q 0 plus Q R of this Q 0 plus Q R, Q 0 minus Q W goes here and Q 0 plus Q R goes here. So, if you sum these 2 Q 0 minus Q W plus Q W plus Q R. So, this get is cancelled and eventually you get Q 0 plus Q R coming and Q 0 Q R leaving this system from these routes.

So, that is how the discharge is maintaining maintain, then this the biomass and the biomass and substrate which is coming if in the effluent comes to here since, there is no reaction taking place. So, there is no change in the substrate concentration substrate is the one which is in the dissolved states. So, there is no change in the substrate concentration and the same substrate concentration goes in the effluent as well.

So, this becomes your effluent BOD, this becomes your effluent BOD and the concentration which is get x of biomass which is getting in the system that is getting changed, because of the phase separation process. So, since the biomass is settling. So, the biomass in the effluent or in the water will be very low which is actually X e biomass in the effluent and as your saying that, it is often considered as 0 and the biomass which is settling. So, that concentration is going to get change. So, that becomes X R the biomass concentration in the solid concentration or the VSS in the water which is actually coming out of the sludge channel.

So, the Q W plus Q R which actually flows out of this has a biomass concentration of X R and the BOD concentration here, again is S because there is no reaction here. So, whether like liquid going towards this way or this way that dissolve BOD levels are essentially the same. So, is the dissolved BOD levels are essentially the same. So, this S remains here, this S remains here, this S remains here this S remains here. So, soluble BOD remains everywhere same whereas, the biomass concentration will change, because E is going into the effluent and X R is the one which is coming down. So, this is X R now of this flow Q W plus Q R Q W is wastage. So, that will have Q W S into X R and Q R is recycled. So, Q R S and X R is the one which is recycle that way.

So, this is the process description what actually happens in a activated sludge process. So, will end this session here and in next session will quickly talk about the how it is design, how the mass balance in a activated sludge process is considered and briefly

speak about some of the other aerobic units which are used as a secondary biological treatment.

Thank you.