Wastewater Treatment and Recycling

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Lecture: 32
Biological Treatment of Wastewater : ASP,TF and RCB

So, we have reached to the last lecture for this week, where we are going to talk about, the biological aerobic Biological Treatment units, Activated Sludge Process, Trickling Filter and RCB to name a few.

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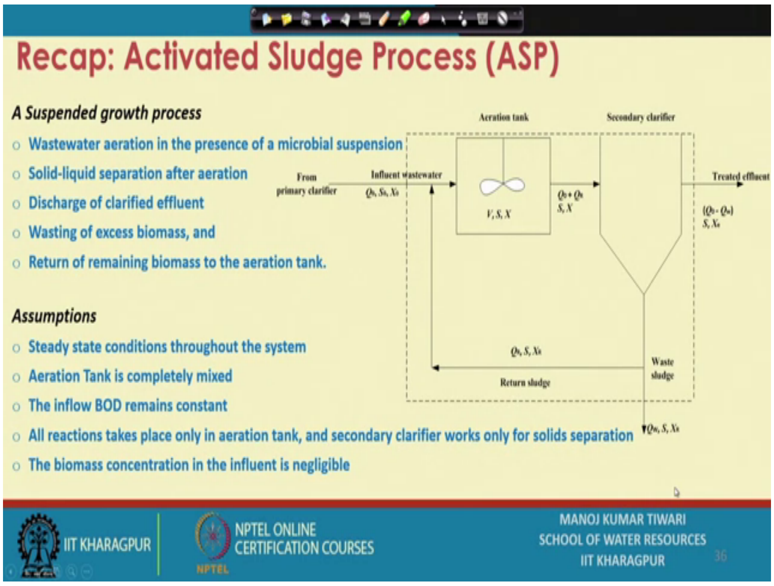

So, this we have been discussing in the previous lecture also that, what processes takes place in activated sludge process. So, how the effluent from the primary clarifier comes, then reaction takes place in the aeration tank and settling takes the phase separation takes place in the secondary clarifier, the effluent goes away, then out of the sludge which, comes part of sludge is actually wastage and part of sludge is recycled back to the aeration tank. We discussed about the various assumptions that are taken, for the designing or modelling of the activated sludge process.

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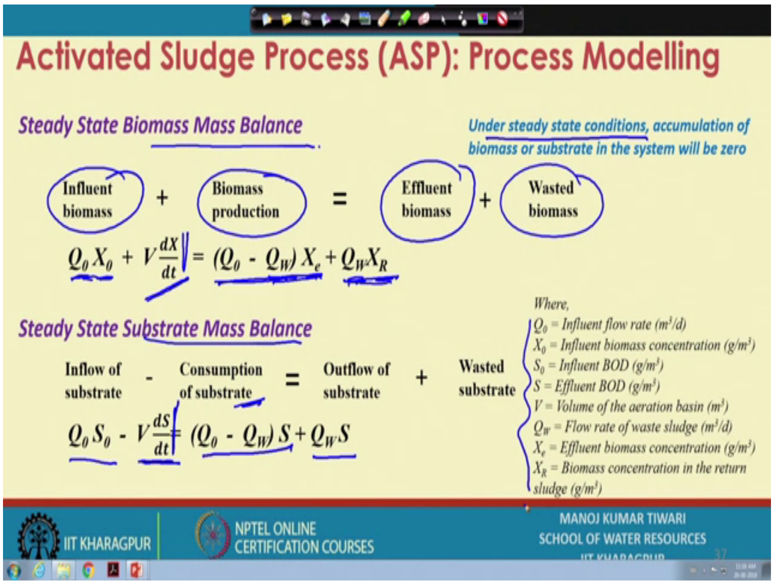

So, if we see under the given conditions, so there is two things, which are there in the activated sludge process; there is biomass and there is substrate ok. So, biomass is produced in the system and substrate is decomposed or degraded in the systems. So, both of these undergo some changes and if, we can actually track the mass balance of both of these constituents we can design or we can model the activated sludge processes. So, mass balance if you see, we are considering mass balance under steady state conditions because, that assumptions we already considered. So, the accumulation of either biomass or substrate in the system is not taking place because, it says steady state condition.

So, what happens that, the influent biomass, the biomass which is coming if, we see the mass balance of the biomass first steady state biomass mass balance, so the influent biomass, which is coming in the system plus biomass being produced, would be equal to the biomass leaving with the effluent and biomass, which is actually being wastage So, what is coming in the system, Q 0 is the discharge, initial discharge and X 0 is the initial concentration. So, Q 0 plus X 0 rate of biomass production if, is net rate of biomass production is d X by d t so V times d X by d t is then, total biomass being produced.

Because, V is the volume of the aeration tank over here, then the biomass in the effluent, X e is the concentration in the effluent and Q 0 minus Q W is the flow of the effluent and Q W is the flow of the wastage sludge and X R is the concentration of biomass in the wastage sludge. So, that is amount being wasted, this is amount actually leaving with the effluent, this is the biomass production and this is the biomass in the influent. Similar way we can write for a substrate as well, the steady state substrate mass balance where, inflow of the substrate Q 0, S 0 corresponding. Substrate is not being produced, but is actually being consumed. So, consumption of substrate it will be, minus V d S by d t and all others to this term.

So, rate of biomass production is d X by d t, rate of substrate consumption is d S by d t. So, that way it is negative term over here. And then, outflow of the substrate again similar Q 0 minus Q W into instead of X e, we will use S and Q W into S, is the wasted substrate along with the sludge line So, these are the traditional conventional biomass equations, where these are the basic notations which, we have discussed which we are just looking in the earlier image as well.

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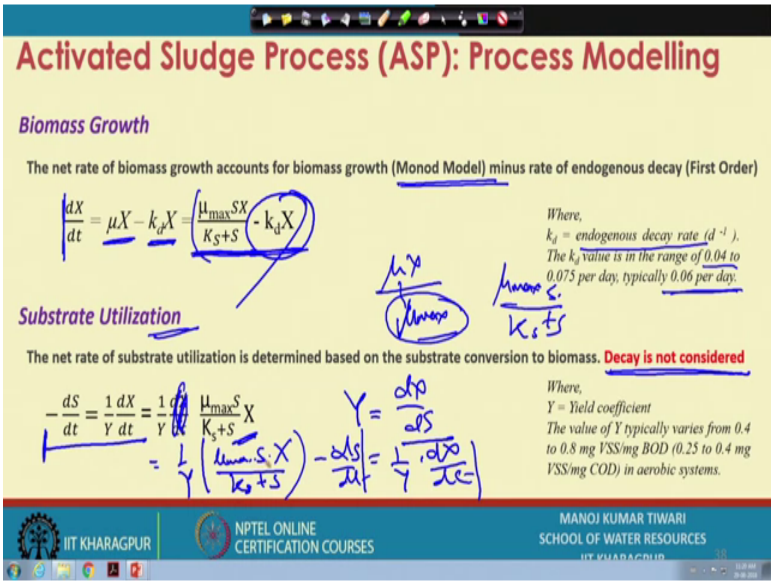

So, now if you see, the two term, which we had in the equations; one is the rate of biomass growth d X by d t, so rate of biomass growth or net rate of the biomass growth, accounts for the growth of biomass mu into X. So, as we were discussing, in the week before in the lecture 3 third lecture of this V. So, the rate of biomass growth is or the how the biomass grows is mu into X and we said that, once it is exponential your mu is equal to mu max, but in often, most of the conditions it is not exponential and we have a kinetic monod kinetic kind of system. So, usually monod model is used and then your mu actually becomes mu max into S divided by K S plus S ok.

So, that is the growth term. So, growth term here became mu max into S, K S plus S and this X comes over here, so as we discussed earlier. So, this becomes your growth term but, there is a indigenous decay of the biomass that also takes place, the natural decay because of the respiration and those kind of things. So, that rate decay rate has to be subtracted, in order to get the net biomass growth in the system. So, this is positive and then k d into X, which is typically considered as first order, if k d is the decay coefficient. So, k d here is the endogenous decay rate ok, this typically 0.06 per day, with value is taken for aerobic heterogeneous mixture value could range, typically from 0.04 to 0.075.

So, that way we get, k d into X as a negative term and net biomass growth rate becomes, your mu max S X divided by K S plus S minus k d into X. Substrate utilization if we see, so remember the concept of biomass yield that, we discussed ok. So, biomass yield is how much biomass is being produced per unit, substrate consumed ok. So that way, as we say that we will get d S is equal to 1 by Y d x; of course, the sign has to be negative, if you divided it by d t both side, so we get d S by d t is equal to 1 by Y d X by d t. So, d S by d t essentially is 1 by Y d X by d t ok. Now this will actually be equal to 1 by Y. This thing has to be go away. So, 1 by Y and d X by d t we can substitute from here.

So, d X by d t, which is rate of biomass growth is mu max into S into X divided by K S plus S. We are not going to consider the decay component in the substrate utilization because, the decay of biomass has nothing to do with the substrate. It is the growth of biomass, where substrate is consumed. So, for the rate of change of the substrate when we are considering, this rate of change of the substrate, we have to consider only the growth aspect of the biomass and not the decay. So, decay will not be considered, when we take the d X by d t for substrate utilization purpose ok.

Whereas, when we are monitoring the amount of biomass, so there endogenous decay will be considered because, decay is leading to lessen the biomass present in the system; whereas, for substrate utilization since, decay has nothing to do with the substitute decays not actually producing substrate right. So, that way since it has nothing to do with that, so we get this as 1 by Y mu max S X K S plus S that becomes the substrate rate of substrate utilization ok.

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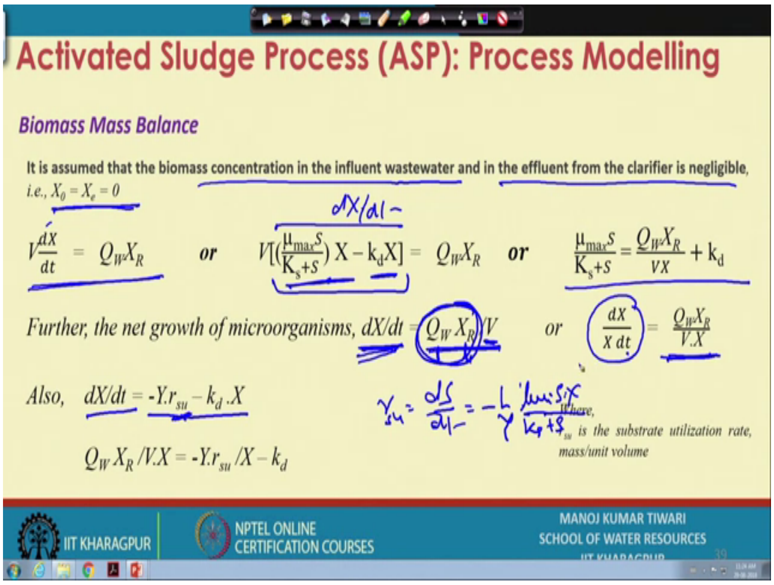

Now if, we see the again using these rates, that we just discussed if, we again have a look at biomass mass balance and with the basic assumption that, we considered that X 0 and X e is 0 means, there is no biomass coming along with the influent and biomass wash out from the system is also 0 ok. So, assume that biomass concentration in the influent wastewater and in the effluent from clarifier is negligible then, we get these things as 0. So, the our basic equation reduces to this, V d X by d t is equal to this. Now here d X by d t we can replace as we were just having a look.

So, this equation reduces to this or we can rearrange this equation to this form ok. So, now, we get a equation like this, further what we can see that, net growth of the microorganisms d X by d t is equal to the because, it is a you consider this way that it is actually a steady state process ok. So, the amount of the biomass growing in the system, net amount of biomass growing in the system has to eventually equal to the net amount of biomass being wasted right. So, that is how the biomass, so if Q W is the wastage and X R is the wastage of biomass. So, this is the mass of bacteria or total biomass, which is being wastage per unit volume of the aeration tank and that is what, should actually be equal to the rate of net growth of biomass ok.

So, if from here we can actually rearrange this, we can write d X by d d X by X d t as Q W X R by V X. Now so, that is one aspect, the other thing is that d X by d t is also equal to the like, if you see that basic equation over here ok, so, this mu max X by K S into X is actually the rate of substrate utilization r s u, which is actually nothing, but d S by d t that way So, at what rate substrate is being utilized and as we discussed that, this is going to be minus 1 upon Y and this mu max into S into X upon K S plus S ok.

So, if we substitute in this equation ok, the typical biomass growth equation because, this is what is actually d X by d t, so, in d X by d t, if we substitute this term with like, this term with r substrate utilization rate, so this becomes like in this equation. So, this term is substituted by minus Y into r s u and k d into X remains in there ok. So, and d X by d t, we can like d X by d t by X this way, so, let us consider it this way So, we have this equation over here ok.

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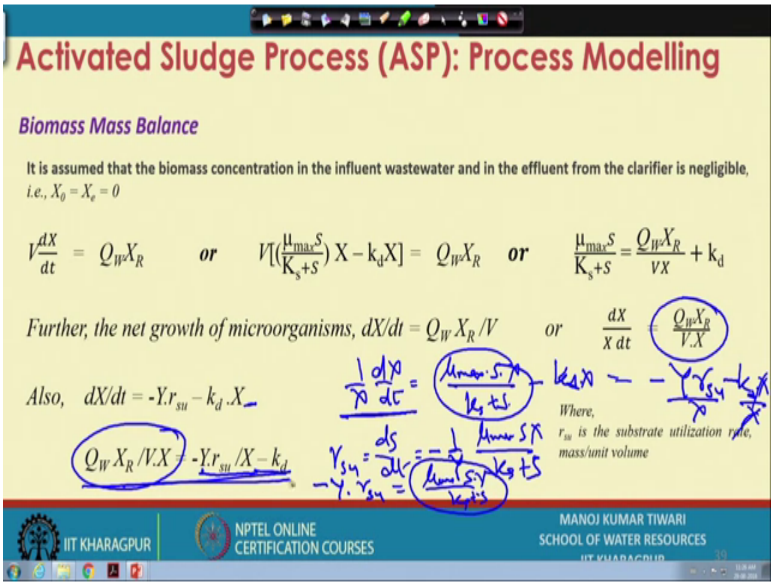

We have this equation over here or to be more clear off, we know that d X by d t is equal to mu max into S into X upon K S plus S minus k d into X. And we know that d S by d t is equal to or minus d S by d t, whatever you write, minus 1 by Y mu max into S into X upon K S plus S. Now this term if, we write this as r s u so, from here from this equation, we will get minus Y into r s u, if you send this Y here is equal to mu max into S into X upon K S plus S.

So, this thing which is here, can actually be substituted by minus Y r s u. So, this will become minus Y, rate of substrate utilization minus k d into X right. It will become this way now, if we divide either side with d X, so what we get here is, 1 upon X here and upon X here and this upon X here. So, X here gets cancelled, so what we get is, 1 by X d d 1 by X d t which is, essentially equal to Q W X R into V X. So, Q W X R divided by V into X is now equal to minus Y into rate of substrate utilization divided by X and here X X got cancelled is equal to k d. So, this is the equation that, we can get out of all this exercise.

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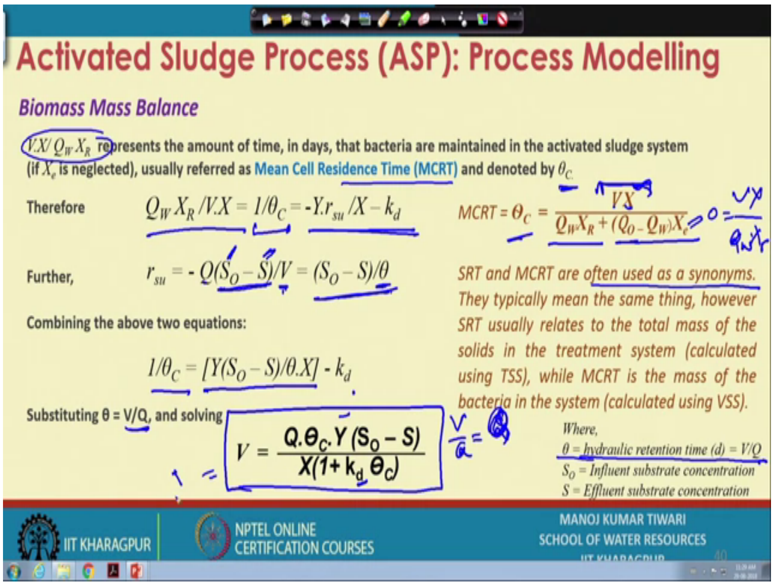

Now, there is as we were discussing in earlier lecture also, when we are talking about this sludge retention time. So, there is another term which is, analogous to sludge retention time and in fact, often used as a synonym for sludge retention time is MCRT, which is Mean Cell Residence Time. So, this mean cell residence time or MCRT is typically, the volume of biomass or which typically can be represented by the MLVSS.

So, the concentration of this multiplied with the volume, so this gives you the total mass of the sludge divided by the wastage of the sludge and the sludge going along with the effluent. So, the two routes through which sludge is wasting ok, so this typically denoted by theta c. Now as per our assumption, the X e is equal to 0. So, this entire term becomes 0 and what we get is V X divided by Q W into X R right. So, this V X by Q W into X R actually, can be represented by theta c ok. Now we had the equation Q W into XR divided by VX which, is inverse of this. So, we can write this as a 1 upon theta c is equal to this over earlier reaction ok.

Now, rate of substrate utilization is again, how the substrate is being utilized. So, S 0 minus S is the amount of substrate, which has consumed. Because S 0 is the inflow substrate and s is the outflow substrate. So, S 0 minus S is the concentration, which has been used Q is the discharge. So, this gives you the total mass and you divide it with the total mass per unit time and you divide it with the volume. So, you get the rate of the substrate utilization. Now V by Q is also known as theta hydraulic retention time. So, for how long, the water is going to stay in the system because, sludge retention time or mean cell retention time refers to the amount of time in days that, bacteria are going to spend in the ASP Activated Sludge Process or particularly aeration tank system whereas, hydraulic retention time is amount of time for which, the water is going to stay there in this thing.

So, if your discharge is Q and volume is V so, obviously your V by Q is actually the value of theta ok. So, theta is hydraulic retention time which is, V by Q. So, from here we get S 0 minus S divided by V by Q or we can write this way as theta. Now if we replace, if we combine these two equations, so we get one upon theta C is equal to Y S 0 minus S divided by theta X minus k d. And we can substitute theta to V by Q and then solve it for V.

So, we get this expression. So this is one of the guiding equation, which is used for designing the volume of the aeration tank, provided we know the kinetic coefficients. So, if we know the decay coefficients ok, if we know the amount like discharge the yield coefficient these things we know, so that we can use this equation for getting the volume of the aeration tank ok. So, that is how a typical aeration tank is designed.

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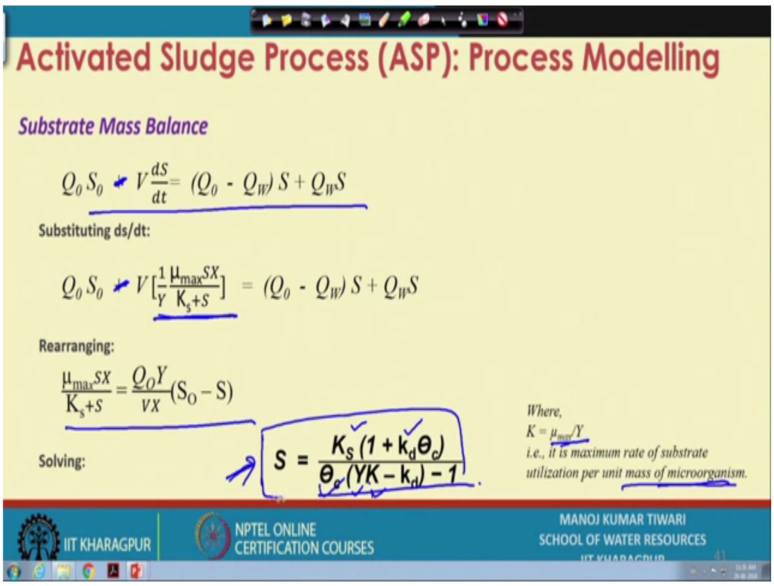

We can analyze the substrate mass balance for getting the effluent concentration as well. So, the substrate mass balance as we discussed earlier is actually this. Now if we substitute d S by d t as we had determined from there, so if we substitute d S by d t like this, so we get this term would actually be negative after substituting this ok, this term is also negative. So, if we substitute it like this, we can rearrange this equation for this and then we will get the final equation of this form ok.

So, here the K constant, is actually mu max by Y, so it is the maximum rate of substrate utilization per unit mass of microorganisms. And this equation can give us an idea of the final effluent concentrations, coming out of the aeration tank ok. So, if we know the kinetic coefficients if we know the K S k d values, yield coefficient theta c all this, so we can determine, we can predict or we can model, what would be the effluent concentrations coming out of the radiation time; considering all those assumptions which, we have already taken.

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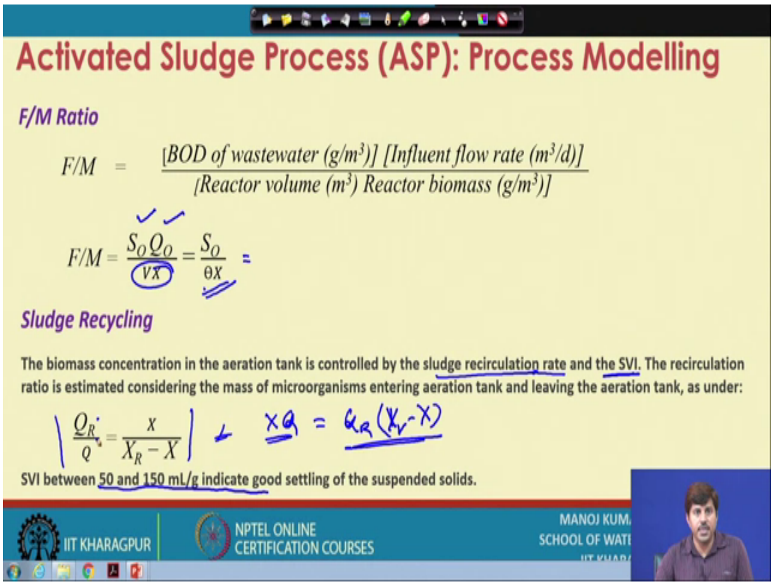

So, that is how the design is done. The other important aspects which actually can be observed is, food to microorganism ratio ok. So, this food to microorganism ratio is the BOD of wastewater, which is coming, which is S 0 multiplied it with the Q 0, so this come gives you the incoming mass of the food and you divide it by the V into X. So, you get the incoming the total microorganism present in the system ok. And we know that your V by Q 0 is theta. So, this reduces to S 0 by theta X. The sludge recycling how much ratio of the sludge recycling is needed.

So, that biomass concentration in the aeration tank is controlled by this sludge recirculation rate and this sludge volume in index. So, this sludge volume index talks about this settling characteristic and 50 to 150 indicates, good settling of the suspended solids. For the recirculation ratio, it is estimated considering the mass of microorganisms entering the aeration tank and leaving the variation tank ok.

So, because we are saying, we want to operate it under steady state ok. So, the mass of recirculation ratio if you see, so mass of the like the X into Q, which is actually there in the system is equated with Q R, the recycle rate and X R minus existing X that way So, this will give you the basically ratio of the recycling. So what ratio of recycling is to be maintained in the system ok, that is another things which is considered for designing purpose.

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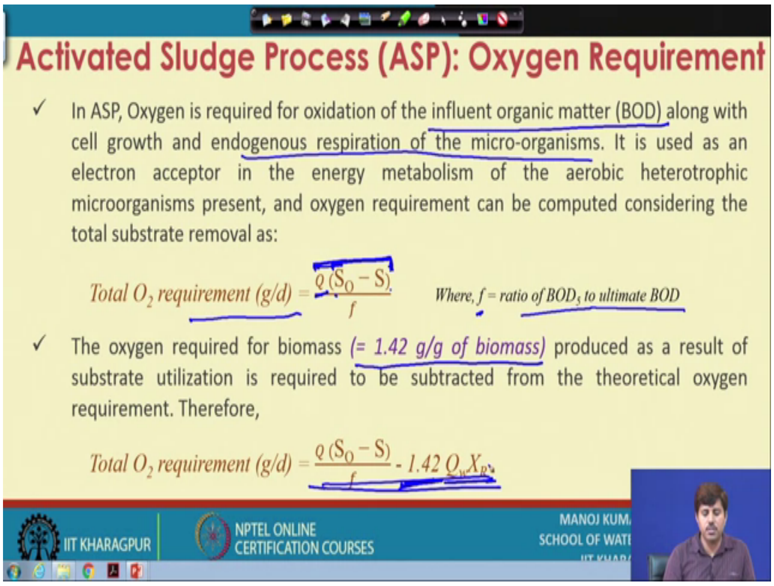

Now there is a requirement of oxygen for the activated sludge process. So, that also need to be insured through aerators. So, oxygen is required for the oxidation of the influent organic matter or BOD, which is there. It also needed for the endogenous respiration of the microorganisms. So, oxygen is basically used as electron acceptor in the energy metabolism particularly, for during the degradation or decomposition of the carbonaceous organic matter, for nitrogenous compound as well though. So, oxygen requirement can be computed based on the total substrate removal. So, if S 0 minus S, if S is your final effluent concentration s is the inflow concentration.

So, this much amount of substrate is being reduced and if you multiply it with the discharge, so this much amount of the total substrate is being reduced in the mass, mass of substrate is being reduced. So, if you know the ratio of the BOD 5 to ultimate BOD f, so that will give you the like because, this is the total mass is removed and if your f is the ratio of the BOD to ultimate BOD, so total organic matter to BOD 5 whatever, you are measuring so, you divide it, where that you get the total oxygen requirement.

The oxygen requirement for biomass, which is actually 1.42 gram, per gram of biomass, so it is for the basically, endogenous respiration of the biomass, which is produced as a result of substrate utilization, needs to be subtracted ok. Because, that is there, so we do not need to aerate for that much amount of this thing. So, if your Q W into X R is the returned sludge, so whatsoever is there oxygen being additionally provided. So, 1.42 per gram, gram per gram of biomass is there. So, you multiplied it with this factor and then that becomes our the total oxygen requirement ok.

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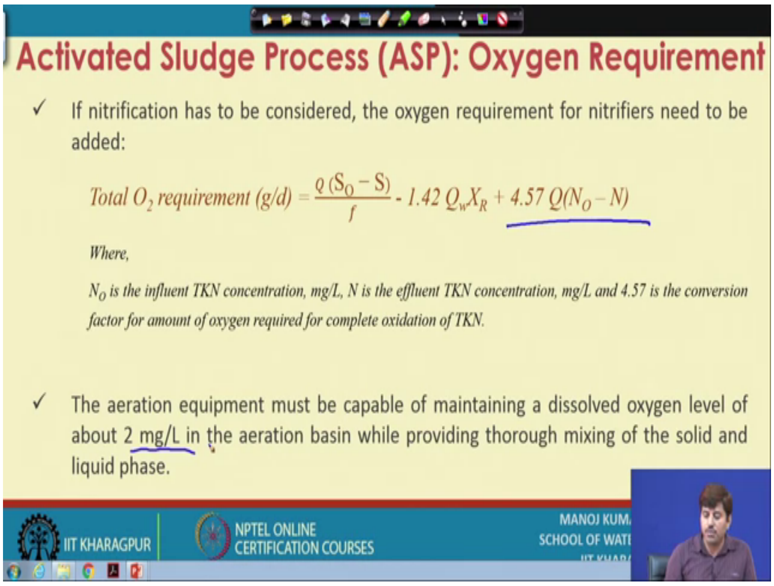

If we are considering nitrification as well, so the nitrification requirement will additionally be added ok. So, 4.57 is the conversion factor for amount of oxygen, required for the complete oxidation of the total zelda nitrogen. So, that additional factors also comes in. So, the aeration we should ensure in such a way that, about minimum of the 2 milligram per litre of dissolved oxygen is maintained in the basin throughout the mixing and solid liquid phase. So, there is no short supply of oxygen, which is hampering the performance of the activated sludge process.

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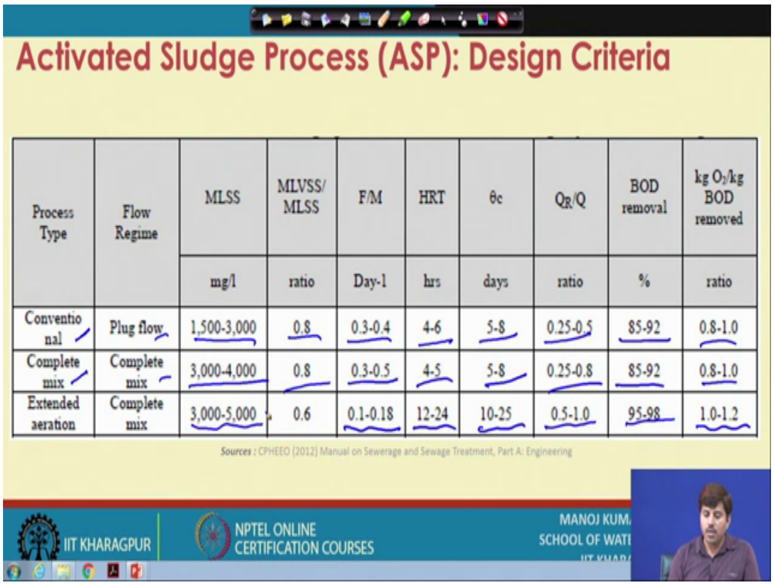

Process Type	Flow Regime	MLSS	MLVSS/ MLSS	F/M	HRT	θc	Q_R/Q	BOD removal	kg O_2/kg BOD removed
		mg/l	ratio	Day-1	hrs	days	ratio	%	ratio
Conventional	Plug flow	1,500-3,000	0.8	0.3-0.4	4-6	5-8	0.25-0.5	85-92	0.8-1.0
Complete mix	Complete mix	3,000-4,000	0.8	0.3-0.5	4-5	5-8	0.25-0.8	85-92	0.8-1.0
Extended aeration	Complete mix	3,000-5,000	0.6	0.1-0.18	12-24	10-25	0.5-1.0	95-98	1.0-1.2

If you have a look at the design criteria's, so there is as per the CPHEO manual, depending on the like if, you have it is a conventional system mixed or plug flow kind of system, So this is the range of MLSS, this is the ratio of MLSS to VSS, food to microorganism ratio, we need to maintain somewhere between this the hydraulic retention time. The sludge is 5 to 8 days, the recycling ratio is 0.25 to 0.5 here in the plug flow type and 0.25 to 0.8 in the conventional mixed type. The BOD removal is 85 to 92 percent. Here same removal is obtained in this one as well and kg of oxygen per kg of BOD is removed, requirement of oxygen is of this order.

Under the extended aeration of course, requirement of oxygen increases, the performance also increases, the recycling ratio also needs to be higher, they provide higher sludge's because, its extended period retention time increases. Food to microorganism ratio we can reduce though because, it is doing done for extended period. So, that is the range of MLSS present in the system. So, this is the typical design parameters, which are used for the design of activated sludge processes.

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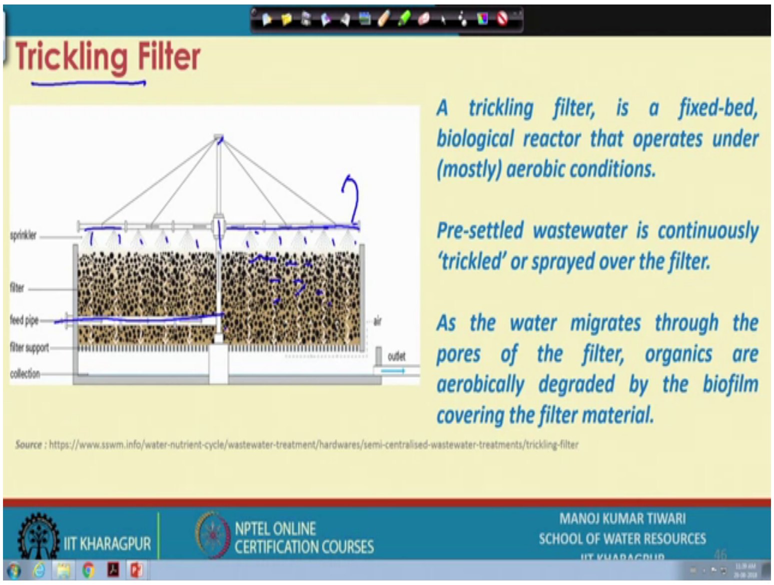

There are couple of more units, which are not as popular as activated sludge process. But still quite frequently used; one is one of the common such units is trickling filter, which is actually a fixed bed biological reactor. So, the activated sludge process being essentially a suspended growth system, now the trickling filter and rotating biological contactor those kind of units are works on a principle of the attached biomass growth. So, what typically happens that we will have packing media over here, and biomass grows attached to this ok.

So, it is a fixed bed biological reactor, the bed is fixed ok. And that operates mostly under aerobic conditions because as the name suggests, it is a trickling filter. So, the water inflow is taken from here and then it is basically trickled through the various, sprinkled through the various holes over this entire media and this shafts keeps on rotating ok. So, on the entire kind of your entire surface, this water is trickles and then that water flows through this finds a path goes to the down. In the process, when it flows through this media which is having the bio attached, biomass growth the biomass over there or biofilm, which has formed utilizes the substrate and the BOD is reduced from there ok.

So, that is the basic concept of this. So, pre settled wastewater is continuously trickled or sprayed over the filter. We need to ensure that there is suspended solid concentrations are extremely low because, otherwise they will choke these openings through which, the water is being sprinkled. So, as the water migrates through the pores of the filter organics and aerobically organic matters is aerobically degraded by the biofilm, which covers the filter material ok. So, we have a fixed kind of bed, through which the water pours through. And in this process it is spent significant amount of time and the micro present in this attached system reacts with this means, decomposes the organic matter and reduces the BOD in the process; if we see the various advantages and disadvantages of trickling filter.

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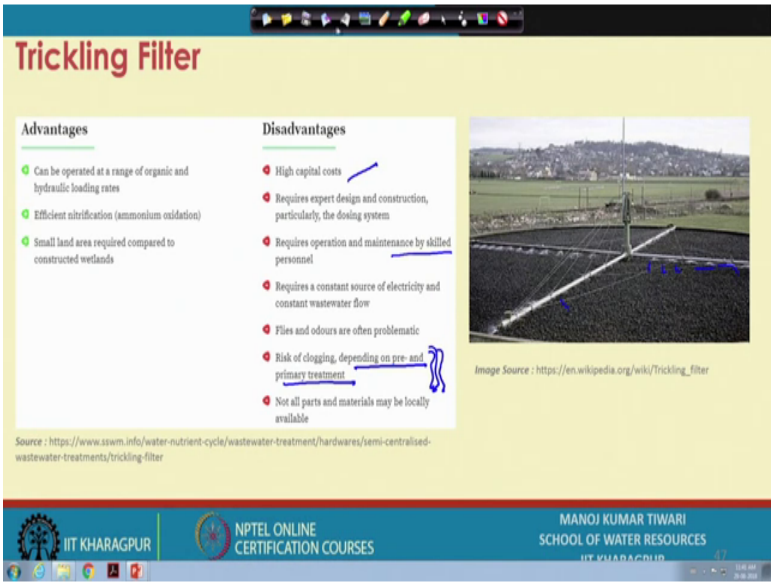

So, this is kind of a actual image of the trickling filter. This is how it looks like, so we will have shafts, which will keep on trickling the water over entire media and this keeps on rotating ok. So, it can be operated at a range of organic and hydraulic loading rates, that is an advantages and it can be basically efficient for nitrification as well. It needs relatively small land area compared to the constructed wetland, not compared to the activated sludge process though. The disadvantages include, the high capital cost, it requires good design, expert design and consideration and the proper dosing system, as we were saying that, their risk of clogging is there.

So, the sediment removal has to be very good ok. The media which is used may not all the materials may not be locally available, further it requires the constant source of electricity, as the wastewater flows constantly. So, that is there with the activated sludge process also and it requires good degree of operation and maintenance. So, these are the major advantages disadvantages. The main one is actually, there is a risk of blocking because, we are letting the water flow through this and once, the it works there is a biofilm formation on the packing media.

So, when the biofilm grows too much, there is a substrate diffusion limitation occurs which, may lead to the washout of the biomass and that can actually clog and there is a high pressure drop in the system in that cases ok. So, those that time, the system may fail and that risk of failure is actually one of the biggest issues with trickling filters.

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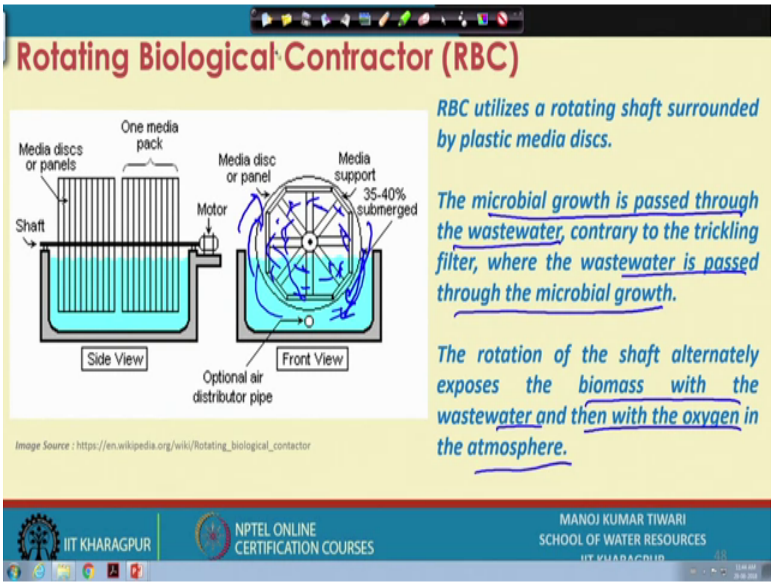

There is RBC which is rotating biological contactor ok. That again is the system, which actually works kind of on a fixed media basis. So, what happens that, it utilizes the rotating shaft, which is surrounded by the plastic media discs, generally we can use other kind of things as well. So, what happens that, there is a shaft there is there is this shaft actually and this the if you see the front view, so this kind of media, this kind of sort of panel is attached with this there is a media disc, which is actually filled with the various plastic media ok, and these shafts keeps on rotating in the water.

So, it is half almost half dip or 40 percent dip in the water, 40 to 50 percent dip in the water and rest of the portion is exposed ok. Now the advantage over here is that, we do not need to supply oxygen because, when we rotate it with the shaft what happens that, there is a cycle developed. This portion which is exposed in the air will actually like, if it is rotating like this. So, this portion which is exposed in the air, will get into the water and the portion which is already in the water, will again come back into the air, so this will get back in the air.

So, the air supply is not provided with the aeration system, but as the shaft rotates, so the microorganisms which are growing over here, when they come into the water, they get the food or they get opportunity to degrade the substrate, but when we when they get in the air, they can actually like these, air requirements or dissolved oxygen requirements are also being made that way ok.

So, conceptually it is similar to the trickling filter process, where the microorganisms attach to these media, when they come into the contact of water, they degrade is decomposed it. Only thing is in trickling filter what happens that, the waste water is passed through microbial growth. So, we have basically a packed medium and the wastewater is being passed, through this medium. So, that is what happens in trickling filter system whereas, in rotating biological contactor it is actually the microbial growth, which is passed through the wastewater. Here the wastewater is not moving, wastewater is more or less there in the system and it is the microbes which are attached all over to this media.

So, they are coming, they are coming in the wastewater and going out of the wastewater, then again coming in the wastewater and going out of the wastewater. So, that is the essential difference here. In the trickling filter, the wastewater is passed through the microbial growth whereas, in RBC's it is the microbial growth, which is passed through the wastewater. So, the rotation of shaft this alternately exposes the biomass with the wastewater and then, with the oxygen in the atmosphere and that kind of fulfils they need for this.

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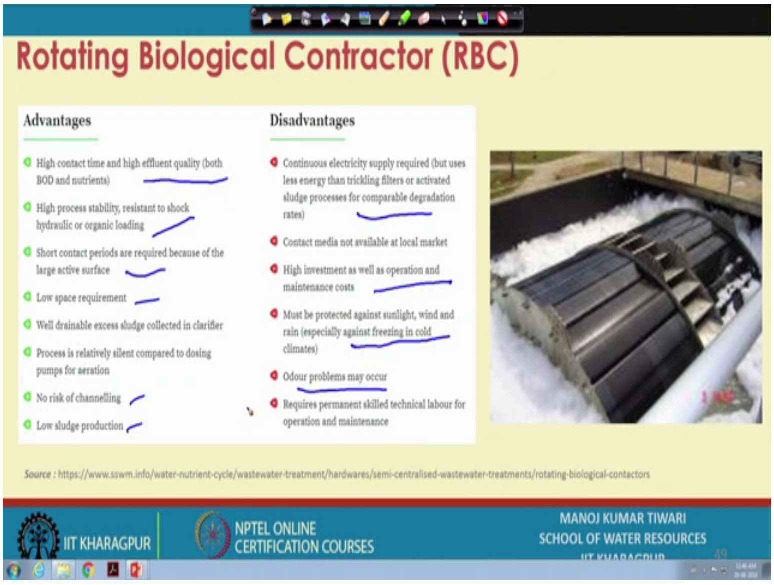

If we look at the advantages and disadvantage real trickling filter, we will look something like this. So, we have packing material and it actually moves in the water. So, it provides a good enough contact time and high fluent quality, both for BOD and for nitrogen and those kind of thing. The process is quite stable, the shock and hydraulic loading it can resist actually because, the biofilm grows and the shock resistance is always better in the when, there is a biofilm formation or when there is a basically the media is attached to something, as opposed to the suspended. Since, when the biomass is in the suspended, it is actually the whenever you provide hydraulic shock, they will quickly get wash out or when you provide organic shock. So, they are exposed to a lot of organic or toxic and concentrations.

And then, they may actually may die pretty soon whereas, in case of attached growth system since, it is attached to a medium, so, even if there is a high flow it can still retain some of the biomass or most of the biomass. So, that retention is better and sustaining the hydraulic shock is better. Same way with the organic shock also, so because the if biofilm has formed, the upper layer might get exposed to the high toxicants, but the inner layer because, it reaches through diffusion, so that way we actually is controlled. The short contact periods are required because, of the large active surface, the space requirements are low, channelling risk is not there, sludge production is low.

So, these are the major advantages; on the disadvantages fund the high investment, as well as operation and maintenance cost is needed because, we need to rotate this soft continuously ok. There is continuous electricity supply and those kind of things needed, there might be odour problem ok. We must protect against sunlight wind and rain because, those kind of things can affect the biomass, that way and required permanently skilled technical labours.

So, these are some of the demerits with this. So, that way, we have sort of like seen that, these are the different, there are many other systems which, we will be discussing when, we go towards the hybrid system in the later weeks. For the time being will conclude these discussions here ok. And so, we have discussed the theoretical part of course, we will upload or we will provide some supplementary material, over with some problem and their solutions in the detail as a supplementary material, that will be uploaded separately. But, the theoretical discussions will conclude here for this week.

So, thank you and see you next week.