# Water and Waste Water Treatment
**Prof. Bhanu Prakash**
**Department of Civil Engineering**
**Indian Institute of Technology-Roorkee**

## Lecture-18
## Analysis of Biological Removal Process (ASP)

Hello everyone, welcome back to the latest lecture session, a quick recap of what we have been up to, we have been discussing the relevant aspects of biological treatment. In that context we looked at different kinds of biological treatment and what are the different compounds or the process that are relevant. We know that organics or organic BOD or BOD needs to be removed.

We looked at nitrification and denitrification, we looked at phosphorus removal. These are the 4 major processes typically that we are concerned with. In that context we started looking at activated sludge process, in that context we looked at how do microbes grow or what are the equations that can help me understand how these microbes grow, what are the rates of microbial growth.

We looked at that and we looked at 2 cases when the food or our waste or the substrate is high when its low so on and so forth we looked at that. We will have a quick recap of those aspects too, but in the context of what we are going to discuss today I need to h refresh your memory regarding some aspects, we are going to understand how to analyze or design the activated sludge process or for that matter any process, any biological process.

We are going to use some terms which we are going to look at fine, but as discussed in the initial lectures of this course we saw that when we are analyzing any process or unit process where different compounds come in along with some flows, they leave along with some flows and they are being transformed within some h or due to some reactions.

How do we analyze this system? How do I design such systems? How do I make sense of it? to be able to make sense of it we understood that or we applied the principle of mass balance. mass coming in, mass going out and mass being transformed these 3 aspects will give us an idea about whether the compound is accumulating within the reactor per time or with time or its decreasing with time regime.

Consider these aspects ladies and gentlemen the key aspect is mass balance**.** You will use that throughout environmental engineering and certainly and water and wastewater treatment. Thus we already discussed the 3 kinds of ideal reactors and applied the mass balance earlier in the course**.** We will use those principles here. We are going to look at some derivations.

In general we do not go into detailed derivations because this is an UG course pardon me, but here we are going to look at the derivations in some detail but these are not complex derivations, it is just mass balance, mass coming in, mass going out and mass being transformed inside the reactor, why do we need to look at these derivations because many plant operators or many people out there do not look at the underlying assumptions before applying the formulae.

And obviously as is the case with any formula you are going to have different assumptions out there without understanding the underlying aspects if you apply the formula you will face one stumbling block after the other in this particular aspect which is crucial to biological treatment and thirst to wastewater treatment we are going to look at mass balance in understanding how things work and then to help us design the relevant systems**.** Let us move on here.

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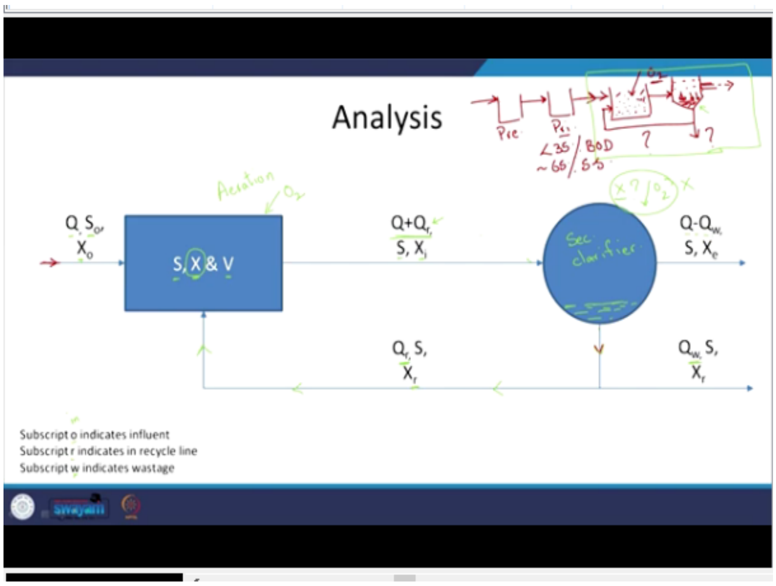


I know that I have my head works or preliminary treatment and then my primary treatment where I am removing the preliminary treatment, primary treatment and now here I removed some BOD maybe 30% 35% or less than 35% BOD removal, maybe 70 or 65% suspended solids were removed may be 70 or 65%. , here you are still left with the considerable organic content which is dissolved primarily and you want to remove that.

how do we remove that as mentioned we are going to use microbes and we are going to provide oxygen that the microbes use their enzymes or catalyze this particular degradation of our waste or their food with relevant enzymes and you are going to fasten or improve the kinetics. We saw that microbes use the h compounds or our wish for 2h processes one is for energy generation, one is for cell synthesis.

And the electron acceptor in the overall reaction if I may say so is oxygen that is one aspect to keep in mind. What happens here in this biological process that you have to give oxygen input there is not enough oxygen in the wastewater obviously and you are going to have the microbes out here and they are going to while using or consuming oxygen degrade your waste or their food which is the substrate.

And then the kind of microbes that are going to be formed they can be settled down and removed from the system if not you will have issues with microbes or high microbial concentration and organics leaving the system. the supernatant will be clear and here this is the water, the supernatant will be clear while the flock forming microorganisms which are relatively heavier, they are going to settle down.

These we will send to treatment why because organic content cells**,** cells organic content you cannot just throw it out there it is going to lead to relevant issues, septic issues certainly. You are going to have to stabilize it or degrade it into more stable compounds, but we do not always waste it. For example this is the waste, we do not always waste it.

Why is that? Here in our sewage or in our waste we have some microorganisms but the kind of microorganisms that lead to the degradation of our waste are not typically present, what microorganisms are present here? We do have microorganisms coming in but they are enteric microorganisms which are not going to assist in degrading our waste. Where will the source of microorganisms within this aeration tank.

Why aeration? Because I am providing air and which will contain oxygen. I am going to recycle part of this sludge which has settled down thus it is called the activated sludge process, depending on the need some of it will be wasted and here I am going to get my treated water. that is the process and we are just applying this or going to look at this part of the system today**.**

This part of the system we are looking at it today and where do we see that here? We see the figure out here. This is the aeration tank, aeration tank thus as a poor figure but you understand the typical shape that you want and here you have what we say the which here you have the secondary clarifier or secondary sedimentation tank where you separate the sludge or the microorganisms from your wastewater which is easy to do because they are not dissolved obviously.

The settled sludge is either going out as waste or is recycled back into our aeration tank. That you provide or we have enough microbial concentration inside the tank. If the concentration of microbes is too less obviously the kinetics or the rate at which these microorganisms can degrade the relevant wastewater is going to be very slow. If it is very slow then you need a huge volume of tank which is not feasible. These are some aspects, let us just understand the variables.

Subscript o indicates influent sometimes we have write it as n at least I write that and subscript r indicates recycle as on this is from the recycle flow, recycle and w indicates wastage, what is going out in the wastage? let us just understand this wastewater with the flow rate of Q which has our waste at an initial concentration of $S_0$ or $S_n$, S stands for substrate or waste organic compounds which need to be degraded.

$X_0$ stands for the initial concentration of microbes in general depending on the type of wastewater $X_0$ is typically 0 though there might be microbes they are not the microbes which will lead to degradation of waste. , this is a pretty good assumption. $X_0$ is typically 0 ok, this is the concentration of microbes coming in along with the wastewater. , what is happening here inside the tank we have substrate microbial concentration and volume of the tank, these are the variables that we are concerned with, we look at other variables too.

Here we see that now the flow rate is not just Q, its Q + Qr why is that, we know that some of the settled sludge which is the microorganisms are going to be recycled back. Why is that because you need a high concentration of microbes that is why? Q recycle or the rate of recycle flow is Qr, that is why we have a flow of Q + Qr here and concentration S and concentration X out here of the microbes, they go to the secondary clarifier here there are little to no reactions occurring why is that are we providing any oxygen here?

No we are not first turbulence that would not meet the purpose whatever oxygen is required we are providing that here. There is no oxygen being provided out here. The assumption which typically holds good is that the substrate whatever is coming in will not be degraded in the secondary clarifier, we are only removing the sludge or the microorganisms or changing phase.

They were earlier suspended in the water the microorganisms and this flock forming what we say microbes they are going to settle down that is what is going to happen here and part of the sludge is going to be wasted send for stabilization or recycle to increase the microbial concentration and obviously Q - Qw is what we have out here. I should not have just said Q - Q w, but that is fine, we will look at Q - Qw is the answer out there. This is the system let us understand how to analyze this.

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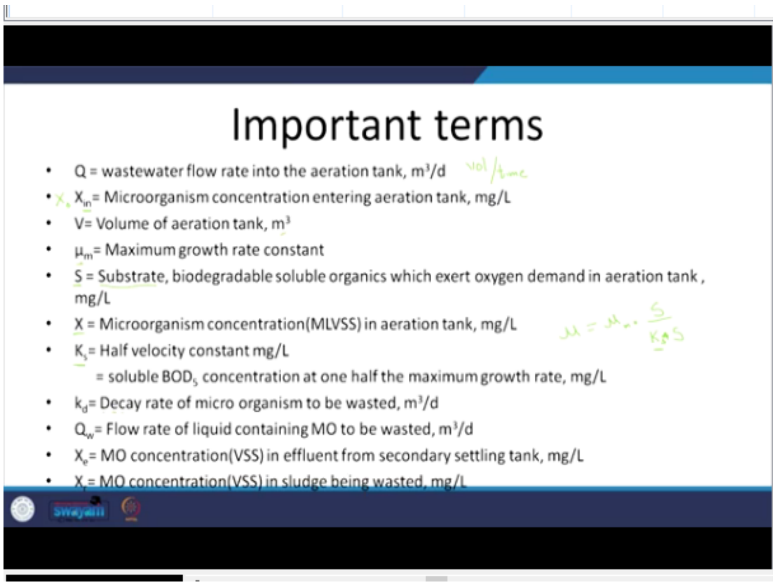


Some terms which I already mentioned Q flow rate coming into the tank, so its volume per time, so microorganism concentration entering the tank. MLVSS different ways to measure we will look at that later, microorganism concentration coming into the tank, sometimes I use $X_0$, sometimes $X_n$, volume of aeration tank, volume of aeration tank not of the secondary clarifier.

We are assuming that there are no reactions occurring within the secondary clarifier, because we are not providing any oxygen to or into the system in the secondary clarifier and without oxygen you would not be able to or the microorganisms will not be able to degrade the relevant waste or the substrate, mu specific growth rate constant or maximum specific growth rate constant which will give us an idea about the microbial growth.

We will look at that later, S is the waste our waste and food for the microbes which is referred to as substrate S, X depending on where we use it is the concentration of microbes, Ks is the half velocity constant which we came across when we said I looked at this Monod equation mu = mu max into S by Ks + S**.** This is what we have we will look at this later or its typically going to be equal to one half the maximum growth rate.

Soluble BOD phi concentration not equal to one half the maximum growth rate, that K s is equal to the soluble BOD phi concentration, that gives half the maximum growth rate and what else decay rate of decay because microbes are going to decay or degrade, wastewater flow containing the microorganisms that needs to be wasted, this will depend upon the mass balance. Concentration of X in the effluent from the secondary tank and concentration of microbes in the sludge that is being wasted or recycled out here**,** these are the general terms.

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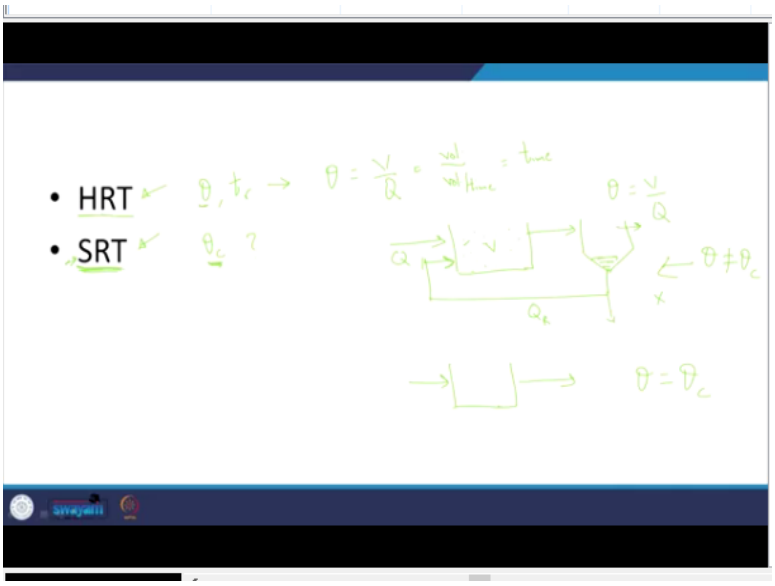


Let us move on here we need to understand 2 aspects, until now we have looked at $\theta_r$ or $t_r$ different people use different variables I typically go with theta, with theta what is theta now it is the hydraulic retention time**.** is theta = V by Q**,** so it is equal to volume of your particular system by flow rate Q is flow rate, flow rate is volume per time**.**

It is at time, but it is not as if time in the general sense, this gives you an idea about theta hydraulic retention time will give you an idea about how much time this particular water molecule or those compounds coming in with the water molecule will spend in your reactor, that is the hydraulic retention time. But here we have a new variable solid retention time which we are going to refer to as $\theta_c$.

What is this now? Let us look at that. Here is my aeration tank, water is coming in, water is going out I can calculate the theta of the compounds in the water or of water theta equal to V by Q, but here in this particular process activated sludge process the system is not as simple as this that from the sludge that has settled out we are bringing in some microorganisms.

How much microbes are present or how much time the microbes are spending in this particular reactor**.** It depends on $Q_r$ , $Q_r$ is a factor, let us look at that later. here we are not just looking at how much time the water is spending in the system, but we are also concerned with how much time your particular microorganisms or which in layman's terms are referred to as solids here are spending in the system**.**

How much time the microorganisms are spending in the system theta c**,** that typically increases because the we have this recycle flow. For example if there is no recycle flow and it is just this then theta will be equal to theta c**,** but in this case obviously theta is not equal to theta c, why is it because the sludge is being recycled within the system while some will leave the system from effluent or from wastage.

in general theta c will be greater than or much greater than theta**,** why is it you want to have the microbes spend more time in the system that they degrade the relevant wastewater. These aspects we need to be clear about. Let us move on to the next aspect**.**

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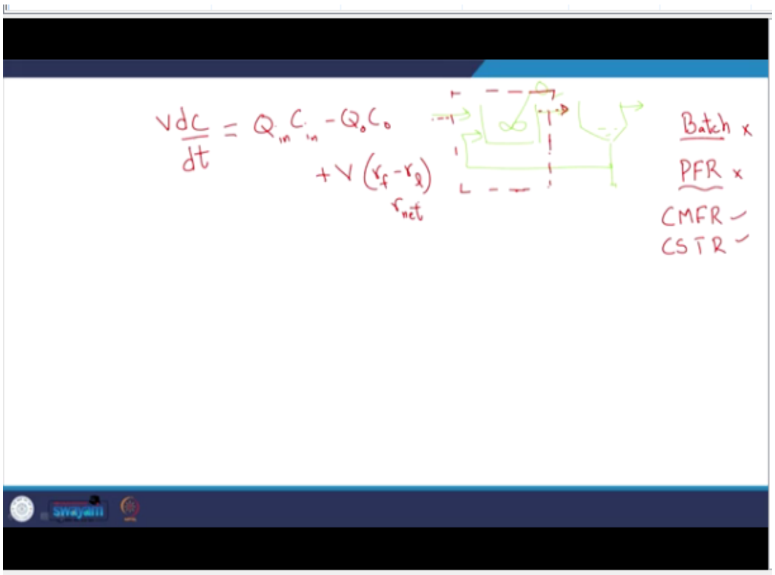


We are going to look at material balance before I look at material balance let us understand the system. We have this water coming in, water going out and this is the symbol that I am going to use for mixing while providing oxygen and then I am going to have this recycle out here and wastage and the treated water will go out through here**.** Here if I look at this particular system out here.

If I look at this system the aeration tank system what do I see? I see that flow is coming in and is bringing waste in meaning mass is coming in and flow is going out along with some waste. Mass is going out and reactions are occurring in the system due to the microbes. Mass coming in, mass going out and reactions occurring. How are we going to analyze the system by applying mass balance?

Here how do I analyze the system? Is it a batch system as in is it a closed system? No because mass is coming in and mass is going out, is it a plug flow reactor? Well with plug flow reactor the concentration of the compound of concern within the reactor is not the same throughout the reactor, but here with continuous mixing and the assumption is that we are mixing it homogeneously.

We are assuming that the concentration is same within the reactor. It is not a plug flow reactor. what is the next aspect mass is coming in, mass is going out, reactions are occurring and more importantly it as completely mixed. It is we are assuming it is a completely mixed flow reactor or continuously stride tank reactor**.** We will apply the mass balance for this particular system considering the system to be a CSTR or completely mixed flow reactor.

What is the fundamental mass balance equation ok, not fundamental the macroscopic mass balance equation? this is the accumulation term how is the mass within the system changing**.** If dc by dt is positive yes it is increasing or accumulating, if it is negative it is decreasing, will be depend upon mass coming in $Q_n C_n$ minus mass going out Q out C out plus volume into rate of formation minus rate of loss of the compound or this I can replace by $r_{net}$. This is the mass balance equation we are going to use and apply throughout this particular session at least for wastewater.

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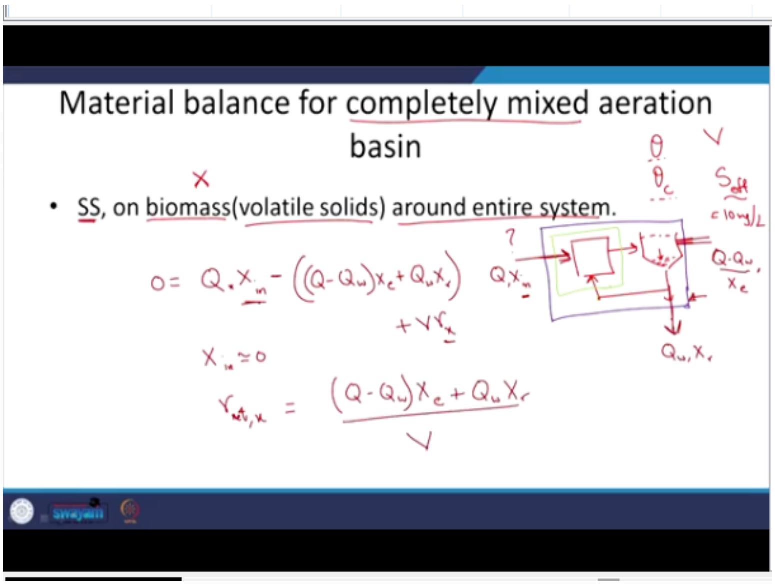


Let us see now what are some of the aspects we need to be concerned about, as we discuss we need to get the theta, we need to get the theta c, how much time do I need to let my water stay in the system, how much time do I need to let my microorganisms stay in the system, what should be the volume of the relevant system if my S in the effluent or waste in the effluent is 10 milligram per liter. I think that is our new standards.

I think we looked at the standards is not it? How do I go about designing these particular variables let us see? We are going to apply material balance obviously as we mentioned it is for a completely mixed aeration basin. We are assuming that it is at steady state which is not a great assumption but we are looking at the long term what we see analysis.

Steady state in that context is a decent assumption. What are we applying the mass balance on? We are applying it on the biomass or the microorganisms which we are referring to as the volatile solids, because that is how we measure that. Volatile suspended solids we looked at a graph or a flow chart where we looked at suspended solids dissolved solids and so forth.

Here we are looking at volatile suspended solids here, and what is the control volume? It is around the entire system, why the entire system as in I know that this is my aeration tank and this is my secondary clarifier where the sludge is being settled down and the supernatant is going out why cannot I just apply the mass balance out here along this or around this green coloured control volume well in that case what is going to happen is I will have an additional variable as in this Q recycle also will come into play.

That will add to some complexity or unnecessary complexity to make it simpler if I choose my particular control volume to be this, this is my control volume obviously, this is wastage. What is it that I am just concerned about mass coming into the system, mass going out of the system and mass being wasted from the system?

These are the 3 aspects and I do not really care what is happening within the system other than the reactions, whatever flows coming when recycle flows inside the system I am not really concerned with it.This is my control volume which we just defined and here we are applying the cons what is it steady state mass balance on the biomass or X. What is the mass balance? We looked at the equation, this is the mass balance**.**

At steady state obviously this term is 0. Now let us apply the other variables out here. dc by dt is 0 what is the concentration of the relevant or what is the mass coming into the system of the biomass it is Q into X in and how is the mass leaving the system, this is how the mass came in Q comma X n mass of biomass are the microorganisms.

And how is it going out some will leave through here Q - Q w and X effluent comma X effluent and here its Q wastage comma X recycle**.** Mass is leaving the system via 2 means so minus because its leaving the system and 1 is Q - Qw into X effluent plus how else is it leaving the system Q w into Xr. That is how it is leaving the system, are there any reactions occurring that can change the system or affect the microorganism concentration in the system?

Yes we know that microorganisms are consuming food and then cell synthesis, reproduction and so forth or growth I should not use the term reproduction and also they are dying to, there is a decay too. There is or reactions are occurring that will affect your microbes. That is what I have out here**.** What else I can do out here, Xn as I mentioned Xn little to no microbial concentration of use to us in the context of which waste water treatment comes in.

I can assume that Xn = 0**.** Now what will I have I can calculate Rx which is r net Xr net X = Q - Qw into Xe + Q w into Xr by volume, we are not going to mug it up, all the general equations that are necessary will be given. But obvious I am talking about the exam here the equations will be provided but you need to obviously be able to understand what are the assumptions behind coming up with that particular equation why? Because we will ask questions or we have to analyze systems where the assumptions are not valid and that is when you need to be pretty thorough.

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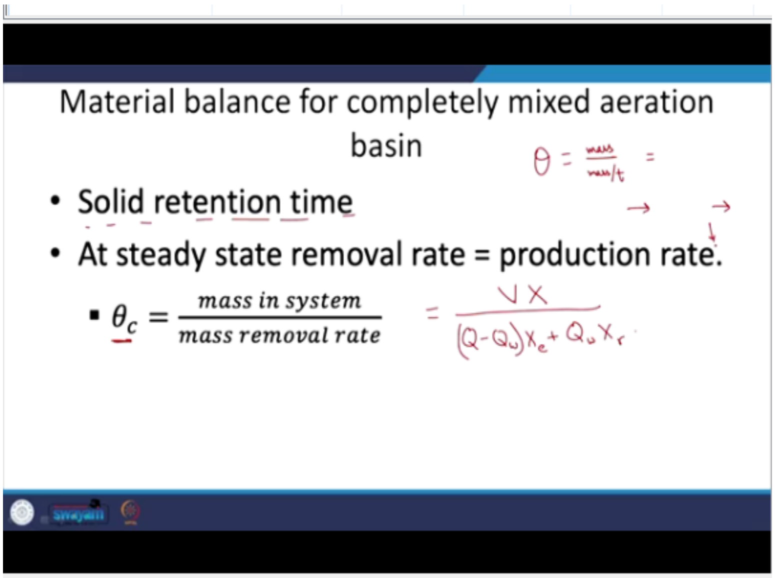


This is what we have this is what I have out here let us keep this in mind equation 1. This is r x net and material balance for completely mixed aeration basin here I want to look at the solids retention time and what is the solids retention time theta c, theta c how do I get that earlier we were looking at what is it volume by flow rate.

But here it is nothing but mass by mass being removed per time. This is the mass of microbes or mass of the solids by mass of solids being removed per time at steady state removal rate equal to production rate fine. theta c in general terms is mass of the solids or the microbes in the system by the rate at which what we say microbes are being removed.

How can I put that in or such what is the mass of the microbes in the system, I know that the volume of my system is V, this is V is of the aeration tank and it is by concentration of the microbes is X, this is within the system the entire system for which we defined the control volume earlier, how is it being removed? I know that mass is coming in X is coming in via the influent? X is going out via the effluent and somewhere the wastage.

How is it being removed? It is Q - Q w into X effluent plus what else is how is it leaving the system by Q wastage into X r. That is what I have out there is not it?

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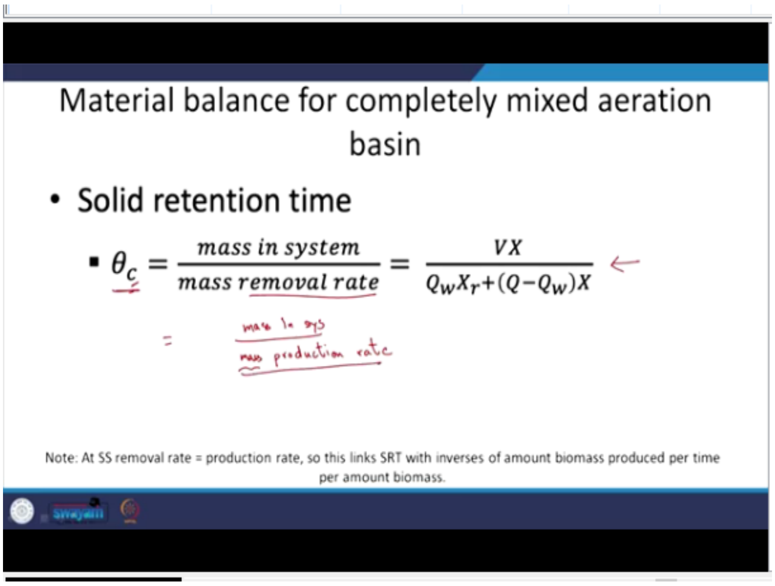


You can look at what I have out here r x net is this and we have what is this theta c to be this. Let us try to combine those 2 aspects**,** before I go further what does it let us look at this under system and try to understand that**.** Suspended solid at steady state removal rate equal to production rate**.**This links the solids retention time with the inverse of biomass produced biomass produced per time per amount of biomass.

For example this can also be written as mass in system by mass removal rate and mass production rate**.** theta c when I say mass it is of the microbes, please keep that in mind when I say **c** theta c cell retention time or solids retention time. theta c is giving me an idea about mass produced or biomass produced per time per the amount of biomass in the system**.**

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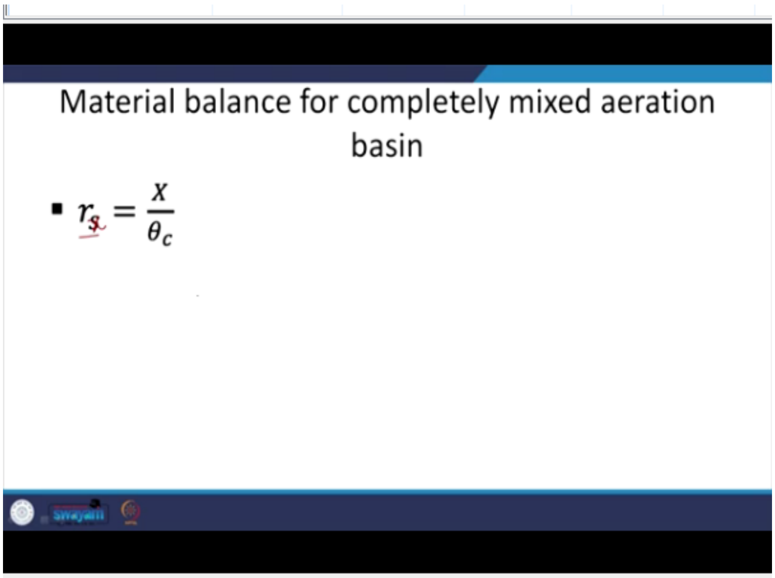


$$r_s = \frac{X}{\theta_c}$$

And then combining this with equation1 which we had earlier what do we see Rs is = X by theta c, it should be Rx This should be Rx net and combining equation1 with the equation for theta c this is what we get Rx = X by theta c, these are aspects we are going to use later, let us keep this aside fine.

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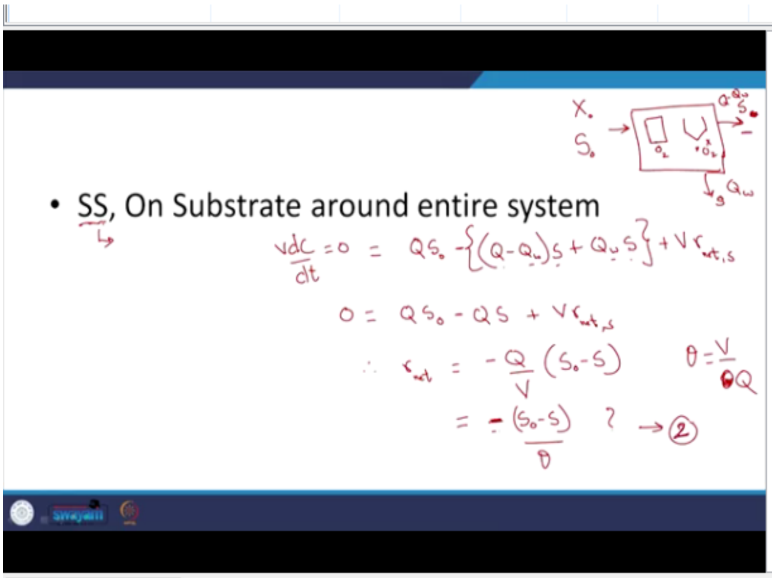


Now what are we going to apply the mass balance on substrate not substrate pardon me suspended solids, steady state on the substrate around the entire system earlier we applied the mass balance on X which is the microbial concentration or the biomass. Now we are going to apply it on our waste or the substrate**.** What is the system? The system is the entire system which includes both the aeration tank and the secondary clarification tank.

Let us just plug this in it us a CSTR that is the assumption, here we are assuming that the reaction is only taking place in the aeration tank, it is not taking place in the clarifier, that is a good enough assumption because oxygen is only being provided here and no oxygen is being provided in the secondary clarifier.

When we take the volume effectively we need to take the volume of the aeration tank only that is something to keep in mind. let us get on with it, so we have mass V = dc by dt because it is at steady state that is equal to 0, that is equal to the waste coming in. It is Q is the flow of waste water coming in, $S_0$ is the substrate coming in, this is S effluent or S**.**

We are assuming the same effluent substrate will leave via Q - Qw and Qw**.** How is the substrate or the waste leaving the system? It is leaving where Q - Qw into S, that is what is happening out here, this is the treated waste water and some is leaving along with the sludge and what else we know that there are going to be reactions occurring. Plus V into r net of substrate that something we have out here, let us just try to analyze this system as you can see - QwS + QwS. They are going to cancel out.

$r_{net}$ of S will be equal to the negative of minus of Q by V, $S_O$ - S and Q by V or V by Q as is theta hydraulic retention time that is equal to minus of $S_O$- S by theta what does this $S_O$ - S , it tells me that the net rate of waste or the substrate is negative.

That means the substrate is being decreased that is what it means r net being negative means it is being removed this is equation 2 or equation 3 let us not keep track here that is what we have out here.

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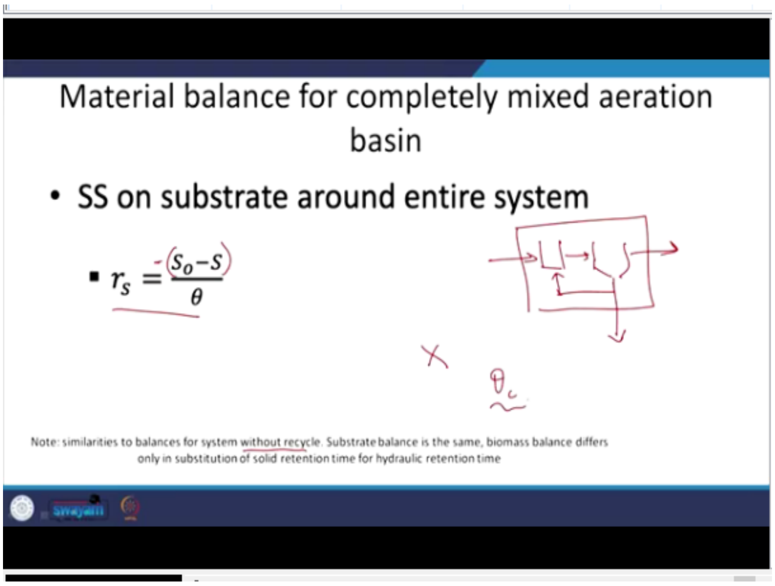


study state so this is negative out here if you have or would have analyzed the system without the recycle For example we know that the system that we are considering has recycle here but we are applying the mass balance around the whole system, because of the way we are taking the control volume what is happening within the system is not of concern.

If you look at it $r_s$ is more or less same as the one for the system without recycle that is what we have. Substrate balance is the same, biomass balance differs only in substitution but keep in mind r s this thing will be the same but if I am applying it on X that will be affected that we can look at it because there we have theta c. that is one aspect to keep in mind.

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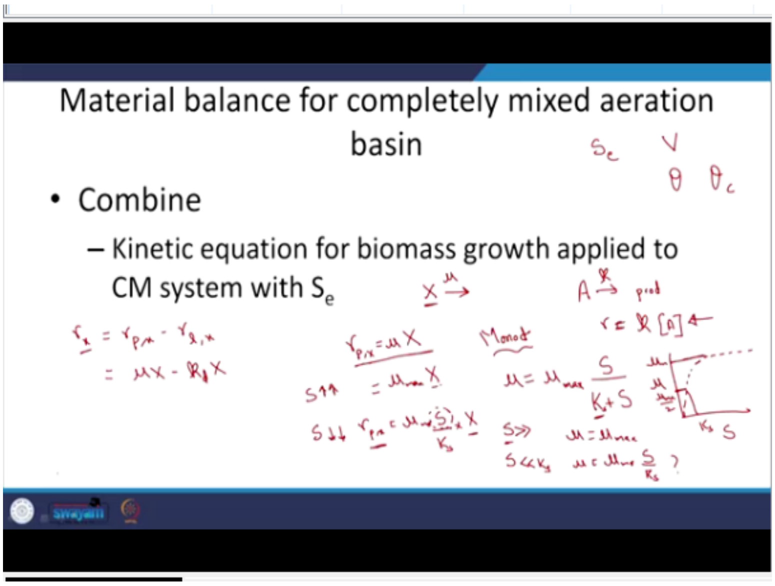


Let us move on what do we have here? We have material balance for completely mixed aeration basin to get at the variables of interest as in I need to be able to calculate S effluent, I need to be able to calculate the volume of the tank theta c,I need to look at these aspects further what is it that we are asking here or going to do kinetic equation for biomass growth**?**

In this context I just need to what do you say refresh your memory with respect to what we discussed earlier. In general if A goes to products what is the rate of this reaction**,** it is going to be equal to a rate constant times the concentration of a here I am concerned about the biomass microbial growth, in general not a chemical in general it is not a chemical reaction.

But here I have X which is the microbial growth which is increasing and the rate constant is mu think of it but where do we get this mu? We get it from the Monod kinetics or Monod equation and how did this equation come out**,** let me not say how what is it equal to mu specific biomass growth rate is equal to mu max into S by Ks + S.

And if I plot this mu versus S what is this going to look like, obviously something like this and this is the mu max and when S or what do we have here K s is when it is equal to mu max by 2, that is when we have Ks**.** , one aspect we discussed earlier was that if S is very high what will that be S is far greater than Ks or S is very, very high then S is far greater than Ks, S ,S cancel out.

mu will be equal to mu max and if S is far less than K s what is it? It will turn out to be mu = mu max into S by K s, why is this relevant, we will just look at that here I need to know rate of production of my microbes. , that will be equal to if I can say in similar terms the specific growth rate into the concentration of the microbes. , if mu is such that or in the case where S is very high you will have mu max into X.

Meaning the rate of production of the microbes is just depend upon the concentration of the microbes that is it. This is the case when S is very high, but the other case when S is very low especially compared to K s, what will that turn out to be rate of production of X will turn out to be equal to what now mu max into S by K s into X meaning it the microbial growth rate will not just depend on the microbe concentration but it will depend upon the amount of food available to that.

That is the case when the substrate is low these are the aspects we need to keep in mind but rate of production is what we have here our net of X is equal to rate of production of X minus rate of loss of X and I know that what is this rate of production of X, this is what I have is equal to mu X minus rate of loss of X that will be depend upon the decay constant which we discussed earlier into X. And what is this r x did we look at this or get this earlier I think we did let us substitute relevant variables out here.

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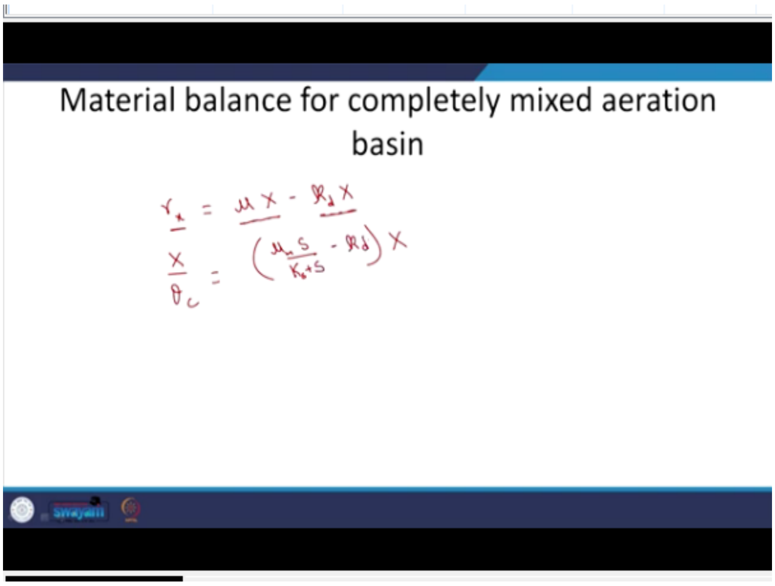


What do we have $R_x$net = mu times X -k d times x, what is this rate of loss, rate of loss of X meaning death of microbes and rate of production of microbes, how are the microbes being produced by taking the food or the substrate. , but did we calculate r x earlier? I think we did, let us go back and look at that equation earlier r x net = X by theta c. X by theta c is equal to I will take X common term out here. What is mu? We know that mu = mu max into S by K s + S and this is - k d.  from here I can rearrange and solve and get this S**.**

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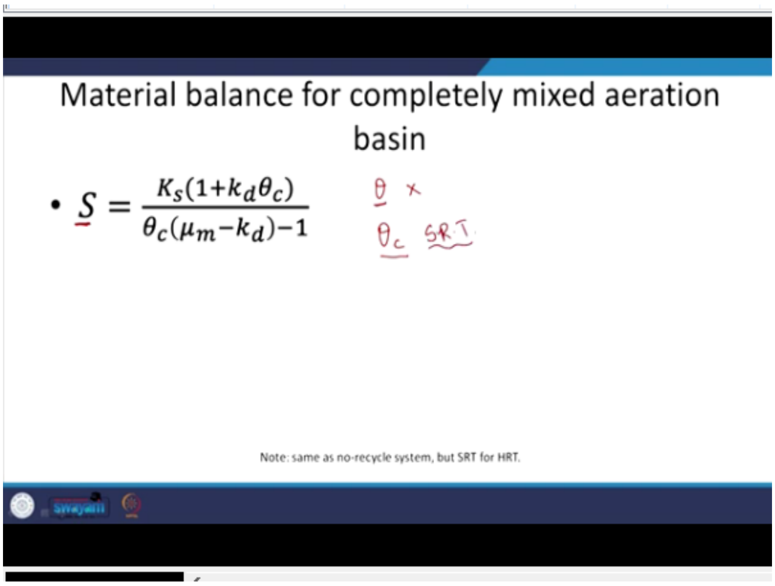


That will give me one of the variables of interest, what is this S here**,** what is the S? S is the concentration of substrate within my particular aeration tank which is more or less the same as what is going out this is depend not on theta, please note that it is not depend upon hydraulic retention time  the concentration of the waste or the BOD in the treated wastewater is not depend upon theta.

But it is depend upon theta c  that is something to keep in mind as and it depends on how long are you storing your microbes in your particular system**.**

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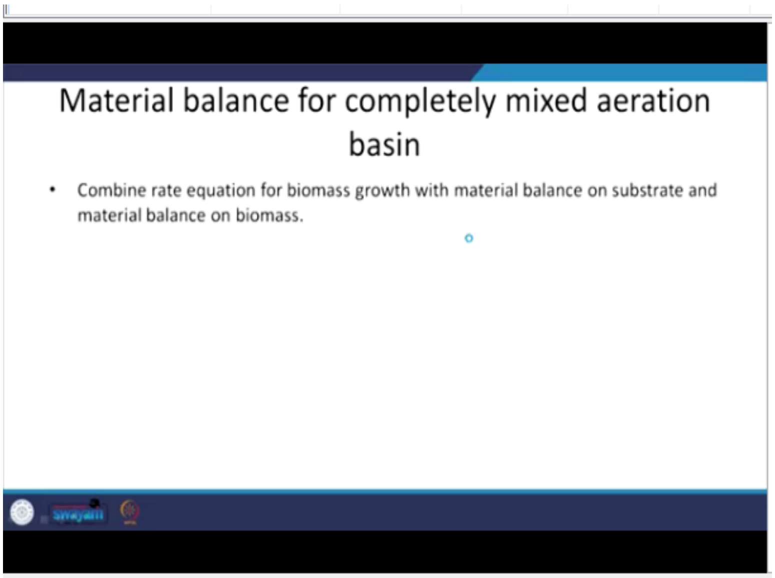

I am just playing around with variables but we need to understand these underlying variables in terms of the mass balance why because most of the assumptions we use to look at the relevant equations are not going to be typically valid.

Only if the mass balance and how to apply it will you be able to play around with the variables pretty easily and get at the relevant variables with that I will end today's session.